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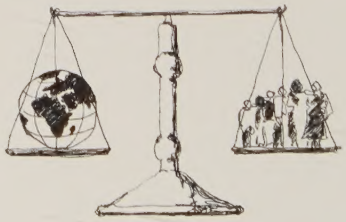

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The role of cooperative business models for the success of smallholder coffee certification in Nicaragua: A comparison of conventional, organic and Organic-Fairtrade certified cooperatives

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Abstract

Supported by policy-makers and non-governmental organizations (NGOs), coffee farmer organizations obtain organic and Fairtrade certifications to upgrade their coffee and, thus, increase returns to their members. Whether this and other upgrading strategies fit into the business model of the cooperative and lead to success are often not considered. This research aims to identify similarities and differences between conventional and certified cooperatives and the resultant impact on farmers' incomes. We analyze the business models, upgrading strategies, and strengths, weaknesses, opportunities and threats (SWOT) of seven conventional, organic and Organic-Fairtrade certified coffee cooperatives and link these to members' coffee gross margins. We use data from over 100 in-depth qualitative interviews and a household survey of 327 cooperative members in northern Nicaragua. Results indicate that cooperatives often apply the same upgrading strategies despite very different business models and SWOT. There are also many commonalities of SWOT among cooperatives but no clear-cut differences between conventional, organic and Organic-Fairtrade certified cooperatives. The qualitative comparison of coffee gross margins among the cooperatives shows no clear income effect from participating in certified coffee production and certified cooperatives. It indicates, rather, dependence of gross margins on yield levels, the business model and upgrading strategies of the cooperatives. Upgrading through certification seems only successful with a suitable business model and other upgrading strategies. Policies should focus on (i) increasing as well as stabilizing coffee yields, and (ii) on the institutional framework of cooperatives by offering strategic support, credit access, external auditing of cooperatives and the establishment of a functional national coffee institute.

Key words: business model, certification, coffee, cooperative, Fairtrade, gross margin, organic, SWOT analysis, upgrading strategy

Introduction

Food products and production processes following environmental, social, quality and safety standards have become increasingly popular among traders, retailers and consumers in industrialized countries[1–6]. In the past decade, organic certified products have moved from niche to mass markets in industrialized countries; a similar trend is likely to emerge for ethical and fairly traded products[3].

The shift in consumer awareness and demand, including the willingness to pay higher prices for certified and/or high-quality products, has also been noticed by farmer organizations and governments in developing countries, non-governmental organizations (NGOs) and international donors[7,8]. To address the deteriorating terms of trade of agricultural commodities[9], price volatility[10] and rural poverty, NGOs and policy-makers recommend upgrading agricultural production and entry to high-value markets[7,8]. This is seen as a way to enhance the

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benefits accruing to producers[11–13]. Coffee producers and their cooperatives can upgrade by offering products with higher quality or additional environmental or social certification or by processing and exporting the goods themselves[7,14–16]. As the food and agricultural commodity value chains have shifted from domestically oriented, state-controlled systems to globally integrated food supply chains with private governance, new forms of vertical coordination have emerged[4]. Cooperatives can facilitate farmers' access to these vertically integrated food supply chains[17]. Each cooperative thereby follows a certain business model: how the cooperative is run, its internal organization and values, as well as services offered such as credit or marketing services.

Farmer organizations, cooperatives and companies are under constant pressure to increase their competitiveness and improve their performance[11]. In the coffee sector, smallholder producers and cooperatives have to defend themselves against low-cost producers in Brazil and Vietnam. The sector is also characterized by frequent over-supply, production shocks and high price volatility[10]. Access to high-value (coffee) markets offers potentially great rewards, but there are also considerable challenges[18].

A typical suggested upgrade for coffee producers is participation in certification schemes such as the organic and/or Fairtrade certification[19–21]. Both schemes aim to increase the welfare of smallholder producers through improving production and marketing processes[14,15,22,23]. The focus of organic certification is on environmentally friendly production processes, whereas Fairtrade certification focuses on social standards and fair marketing and trading conditions. The details on the standards of organic and Fairtrade certification are widely available in the literature[6,24–27]. Although Fairtrade certification is only available to coffee producers organized in a group or cooperative, organic certification is also issued to individual producers. Organic certification costs can be high and often smallholders can only afford certification when they participate as a group. Several research studies have indicated that organic and Fairtrade certification can improve education, health and infrastructure[28,29], and increase social organization and capacity building[30–32]. However, while some studies identified price premiums for both certifications and economic benefits at the producer level in Latin America[30,33,34], other research has found few economic benefits for farmers[14,35–37].

The existing literature largely addresses the socioeconomic effects of coffee certification on smallholders with a focus on farm, household and community levels[29,38,39] but only marginally deals with farmer organizations' business model and upgrading strategies. A separate stream of literature identifies the determinants for successful collective action, group formation, farmer organizations, and resulting advantages and disadvantages[12,18,40–42] but does not focus specifically on upgrading strategies. The fit of upgrading strategies to the business model of a farmer organization as well as the determinants for the success of upgrading through certification have been neglected by research so far. This may partly account for the contradictory findings regarding economic benefits from certification in the above cited studies. Additionally, most of the cited studies on certification effects have neither randomly sampled cooperatives/farmer organizations nor analyzed several cooperatives or certification standards simultaneously. Arnould et al.[28] worked with randomly sampled cooperatives, but did not analyze their business models. Raynolds et al.[30] systematically compare seven, non-randomly selected, Fairtrade certified producer cooperatives in Mexico, Guatemala and El Salvador. The authors find that successful Fairtrade participation depends on the political, economic and marketing conditions, the social and ecological resources of producers, and the producer groups' internal organization and external links[30], yet they did not analyze the latter in depth. As only one certification scheme is targeted and no comparison with cooperatively organized conventional producers was made, the Raynolds et al. study cannot differentiate between the socioeconomic effect of certification and the socioeconomic effect of being organized in a cooperative or producer group.

Raynolds et al.[30] assume that their above identified characteristics have proven to be historically successful but are likely to be insufficient in the future given the growing competition in Fairtrade markets. In this paper, we focus specifically on the roles of the producer groups, their business models and upgrading strategies in the success of certification schemes. We analyze cooperatives with two certification schemes, organic and Organic-Fairtrade, and compare these to a control group of cooperatively organized conventional coffee smallholders.

The following three research questions are analyzed:

(1) Do the business models and upgrading strategies differ between conventional, organic and Organic-Fairtrade certified cooperatives apart from the certifications?
(2) Are there differences in the strengths, weaknesses, opportunities and threats (SWOT) between conventional, organic and Organic-Fairtrade certified cooperatives?
(3) How are the coffee gross margins linked to the organic and Organic-Fairtrade certification strategy, the cooperative's business model and its other upgrading strategies?

We collected over 100 qualitative in-depth interviews from seven cooperatives in northern Nicaragua representing conventional, organic and Organic-Fairtrade certified smallholder coffee producers. We also conducted a two-stage random sample based household survey with 327 coffee producers of the seven cooperatives.

The article is structured in seven sections. The next section presents the conceptual framework. The third section describes the sampling framework and the

analytical methods. In the fourth section, we describe the cooperatives' business models. Section five analyzes the upgrading strategies and the SWOT of the conventional, organic and Organic-Fairtrade certified cooperatives. These results are linked to the coffee gross margins obtained by the cooperative members in the sixth section. The last section contains the conclusions and policy recommendations.

The Conceptual Framework: Business Models and Upgrading Strategies of Coffee Cooperatives

The potential of smallholders to increase their agricultural incomes increasingly depends on their ability to access output markets[12,40]. Farmer organizations such as cooperatives can play an important role in connecting producers to markets. A market-oriented cooperative is characterized by a group of economically active individuals who engage in a joint undertaking with the objective of deriving benefits for themselves as members[43,44]. Over the past few decades, cooperatives have increasingly adapted their organizational structures according to market conditions. This has led to a broader range of cooperative structures than before[44]. Each cooperative, such as a company, follows an individual business model and these business models can be seen as 'stories that explain how enterprises work' (Magretta[45], p. 87). The business models of cooperatives can be classified according to microeconomic aspects such as the main activity (credit/savings, production, consumption and service), the type of economic functions or services (supply/purchase, marketing, production, financing and administration), the number of functions and services, and the degree of organization (informal or formal)[46]. Service cooperatives offer input supply, processing and marketing of outputs, financing, and also provide technology or support to their members in entering high-value markets[12,47]. Agricultural cooperatives in developing countries tend to offer multiple services.

In Nicaragua, cooperatives have a long history. Agricultural cooperatives were founded in the 1930s. In 1979, 634 cooperatives existed, although only 88 really functioned[48]. With the overthrow of the Somoza dictatorship in 1979, the land owned by the Somoza family was expropriated by the new government, the *Frente Sandinista de Liberación Nacional* (FSLN). FSLN strongly supported cooperatives, especially those with collective production. Somozas's property, around 20% of Nicaragua's farm lands, was first turned into state farms and later, as for other expropriated or purchased farmland, handed over to agricultural cooperatives or individual smallholders[49]. Members of the cooperatives could inherit, but not sell, the title or part of the land[50]. The state farms and the agricultural production cooperatives were strongly supported by the government with inputs and credits[49,51]. Especially in northern Nicaragua, the government also used them as political organizations[49]. By the end of the 1980s, 2174 cooperatives existed: 1685 agricultural cooperatives, 58 credit and savings cooperatives, and 73 service cooperatives[48].

The ushering in of a new government in the early 1990s, led to a wave of economic liberalization. Agricultural cooperatives were no longer given preferential treatment and it was permitted to hand over collectively owned land to individual cooperative members. In 1989, rural cooperatives occupied approximately 21% of the agricultural land; by 1999 this figure had been reduced to 9%[51]. Many of the agricultural cooperatives have disappeared since then but some of today's cooperatives still have a history related to the former politically supported cooperatives[51].

Cooperatives in Nicaragua are currently undergoing structural changes in response to a law passed in 2004 obliging them to register legally and to restructure. This has led to a relatively homogeneous organizational structure within the currently registered cooperatives. However, not all existing cooperatives have finished this registration process, largely because they could not afford to pay for the obligatory training of cooperative members and staff. The hierarchical organization of cooperatives distinguishes first-, second- and third-level cooperatives. The first-level cooperative is the lowest level where individual farmers are members. The organizational components of first-level cooperatives are the general assembly (either members or elected delegates), the supervisory board that controls finances, and the administrative board or steering committee composed of the president, vice president and treasurer. The steering committee is supported by several specialized committees, e.g. for education, credits and marketing. A minimum of five first-level cooperatives can form a second-level cooperative and by doing so secure economies of scale in processing, marketing or exporting of products. Second-level cooperatives can then consolidate to form third-level cooperatives or federations. Many variations of this still exist because the law has not yet been fully implemented. The agricultural cooperatives in Nicaragua today mainly offer multiple services.

Shafer et al.[52] define a business model as a description of the underlying logic of a cooperative/company and its strategic choices for creating and capturing value within a value chain. This implies that cooperatives pursue a strategy to create additional value by differentiating themselves from competitors[45]. Upgrading strategies are mainly seen as strategies that improve the position of producers or cooperatives in the value chain through shifting to more (economically) rewarding functional positions, for example through the uptake of new activities previously performed by other chain actors or through increasing the added value of production or improving returns[11,53–55]. In a broader definition,

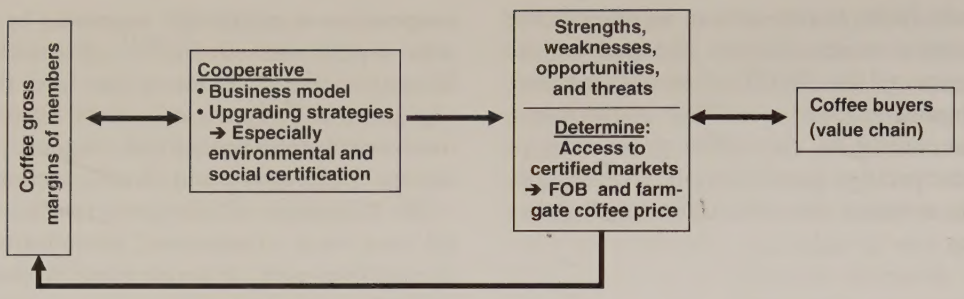

Figure 1. The influence of the cooperative's business model and upgrading strategies on members' coffee income.

upgrading can additionally include a change of activities which leads to reduced exposure to risk[13,56]. This broader definition embraces the possibility of downgrading. For small producers and entrepreneurs in developing countries, Riisgaard et al.[13] identify seven possible upgrading strategies that can be grouped into three types according to (i) the improvement of the product, volume or production process, (ii) the change and/or the adding of functions in the chain, and (iii) the improvement of value chain coordination through horizontal and vertical contracts.

Product improvements can be achieved through increasing quality, complying with certification, such as organic or Fairtrade, or by meeting food safety standards. Improvements of the produced volume can be obtained through increases in yield or area, whereas the production process can be improved through increasing efficiency or reducing negative externalities such as environmental pollution. The change of functions in the chain refers to either (a) functional upgrading, such as taking on new functions such as processing, exporting, roasting or providing services/inputs, or (b) functional downgrading through the abandonment of unprofitable activities and a focus on core activities[13]. Vertical value chain coordination can refer to improving business ties with buyers through contracts instead of spot market sales. For example, cooperatives may contract directly with coffee roasters. Horizontal coordination can be agreements among producers or cooperatives to cooperate over marketing, services or input provision.

To summarize, the conceptual framework builds on the cooperative, its business model and chosen upgrading strategies (Fig. 1). We use the term business model for the cooperatives based on the above-mentioned definitions, but limit the analysis to organizational structure, size, functions, services and financial characteristics. The classification of upgrading strategies is based on the framework of Riisgaard et al.[13] A particular focus is on the upgrading strategy of environmental and social certifications such as the organic and Organic-Fairtrade certification. The business model and upgrading strategies together determine the strengths and weaknesses of the cooperative which are internal factors. External factors emerge from the natural and business environment within which the cooperative operates. They constitute opportunities for development as well as threats. The internal and external factors determine the access to certified markets as well as the coffee prices the cooperative obtains in international markets, and thus influence the farm-gate price a cooperative can offer to its members.

Sampling Framework and Methods

The research was conducted in northern Nicaragua, in the departments Madriz and Nueva Segovia, on coffee farms situated between 900 and 1300 m above sea level. Through pre-study field visits and key-person interviews, we ensured that the research region was homogeneous in terms of living conditions (such as remoteness, hard and soft infrastructure, market access, housing, etc.), the socio-economic level of the smallholders, and the on-farm coffee growing characteristics. The coffee quality of all farmers fell into the 'Strictly High Grown' (SHG) category. This was also verified ex-post by the household survey. Quantitative household data were collected in 2007. Cooperatives were randomly selected from a self-established list as there was no official list of all the cooperatives in the region. The list of existing cooperatives was compiled during several field visits and key-person interviews. We then classified cooperatives according to their certification into conventional, organic and Organic-Fairtrade certified cooperatives, and randomly selected the cooperatives. The coffee growing cooperative members from the selected cooperatives were the population from which the interviewed households were selected. The household selection was done either using a simple random sampling or a two-stage random sampling, depending on the regional spread of the cooperative. Using a structured questionnaire, 327 cooperative members were surveyed with nearly equal shares of conventional, organic and Organic-Fairtrade producers. The response rate was 100%. The household questionnaire included data on the household demographic characteristics, the dwelling, food consumption, assets, access to financial services, agricultural production with a special focus on coffee production and cost data, marketing channels, coffee prices and certification.

One conventional cooperative dropped out of the study near the end of the data collection period. The

Table 1. Questions regarding cooperatives' SWOT.

Strengths • Where do you and your buyers see the strengths of your cooperative? • Which activities of the cooperative are going well? • What have been your most notable achievements?	Weaknesses • What limitations or problems does the cooperative face? • What relevant resources do you need?
Opportunities • Where do you see the opportunities of your organization? • Is there an opportunity to demand better prices from suppliers?	Threats • Where do you see the threats to your cooperative? • Have there been any significant changes in the coffee industry or governmental regulations? • Are there any, or do you anticipate, new competitors in your market?

conventional cooperatives are called CONV-A ($n=37$) and CONV-B ($n=31$); the organic certified cooperatives ORG-B ($n=32$) and ORG-C ($n=76$); and the Organic-Fairtrade certified cooperatives OFT-D ($n=34$), OFT-E ($n=36$) and OFT-F ($n=34$). ORG-B is a subgroup of organic coffee producers of the conventional cooperative CONV-B. If not further specified, we use the term 'certified' to refer to both the organic and the Organic-Fairtrade certification.

In addition, in 2007 and 2008 qualitative data were collected through 48 key-person interviews with cooperative staff, exporters, roasters and researchers, 33 semi-structured producer interviews, and 21 focus group discussions, with an average of nine participants in each group. The interviews with the cooperative staff examined the cooperative's business model, its upgrading strategies, coffee sales, and its SWOT. All interviewees gave their informed consent prior to the quantitative and qualitative interviews.

We used a SWOT analysis to identify internal and external factors that affect the cooperatives and their implicit goal of increasing their member's economic welfare. A SWOT analysis helps to provide a quick picture of an organization's current position and its short-term future[57]. This overview can be used to evaluate the current situation and make strategic decisions about the future[58]. Being a descriptive model it does not offer explicit strategies[57], but provides a transparent overview and reveals important problem areas[59]. Organic or Organic-Fairtrade certification as an upgrading strategy is compared with the 'business as usual' model of conventional cooperatives. The questions listed in Table 1 are the guiding questions used in the interviews with the cooperative staff. In addition key-persons, such as coffee exporters and NGO staff, were also asked these questions to obtain a broader view of the coffee sector in Nicaragua.

In the next step, we link the cooperative business models, SWOT and upgrading strategies with farmers' coffee gross margins. Gross margins are calculated per hectare of coffee. Even certified coffee producers usually sell to various coffee buyers outside their cooperatives. These sales are called 'off-sales'. We calculate the revenue per hectare by calculating the quantity of coffee sold in a market channel, multiplying this by the farm-gate coffee price obtained in that market channel and then dividing that figure by the coffee area in hectares. The farm-gate coffee price is the final price farmers receive after the cooperative or exporter has deducted their costs for coffee drying, processing, transport, administration, fees and taxes. The costs for the organic and Fairtrade certification are reflected in the farm-gate coffee price. Farm-gate coffee prices were discounted in those cases when the cooperative paid months after the coffee harvest. In addition, we indicate the average price coffee producers received across all marketing channels by dividing the total revenue of a farmer by the total quantity of coffee sold. By deducting the variable production costs from the revenue, we determine the gross margin. The variable production costs include all input costs such as organic or chemical fertilizer, pest, disease and weed treatments (chemical and/or organic), transport costs related to the purchase of inputs and coffee sale, the costs occurred at harvest for, e.g., coffee picking, wet processing, sacks, and the costs for hired labor. For a more detailed description of the calculation, please refer to Beuchelt and Zeller[60]. The gross margins of the cooperative members are used to indicate the success of the certification schemes.

The Business Models of the Sampled Cooperatives

An overview of the cooperatives' business models, their characteristics and services offered is presented in Table 2. The two conventional cooperatives focus on offering financial services such as provision of credit as well as savings accounts. Cooperative CONV-A markets coffee through an alliance with an exporter. Cooperative CONV-B offers many additional services such as supplying inputs and storage, as well as grain and coffee marketing. The certified cooperatives focus mainly on service provision regarding coffee-related services such as extension, processing and marketing of coffee. They market the coffee themselves or via the second-level cooperatives with which they have alliances. Except for the cooperative CONV-A, all other cooperatives offer basic coffee inputs such as fertilizers, insecticides or fungicides, or the needed ingredients for home mixtures. The organic cooperative ORG-C additionally produces and sells high-quality organic fertilizer at cost-recovery prices. For a small fee, the cooperative even transports the fertilizer to the member's plots. Through both services members are able to apply more organic fertilizer than

Table 2. Overview of the characteristics and services of conventional, organic and Organic-Fairtrade certified cooperative business models.

	CONV-A	CONV-B/ORG-B	ORG-C	OFT-D	OFT-E	OFT-F
Cooperative type	First level	First-level member of second-level cooperative	First level	First-level member of second-level cooperative	Second level, composed of eight first-level cooperatives.	Second level, composed of six first-level cooperatives.
Year founded	1998	1994	1999/2000	1999	Restructured in 1992	1996
Total member size	338	9313	130	600	309	168
Type of members	Small-sized agricultural producers, mainly in coffee	Small-/medium-sized agricultural and industrial producers, employees	Smallholder coffee producers	Smallholder coffee producers, some small agricultural producers	Smallholder coffee producers	Smallholder coffee producers
Type of activity: Economic functions and services	Credit/savings and service: Financing, both input supply and limited marketing	Credit/savings and service: Financing, input supply, marketing (limited)	Service: Input supply, coffee marketing, credit (limited)	Service: Input supply, coffee marketing, credit (limited)	Service: Input supply, coffee marketing, credit (limited)	Service: Input supply, coffee marketing, and credit (limited)
Marketing of coffee	Through alliance with exporter (also does processing)	Own dry mill but markets via exporter and second-level cooperative	Own marketing (via exporter who also does processing)	Own dry mill, own marketing and via second-level cooperative	Dry mill contracted, own marketing, has export license	Own processing and marketing, has export license
Other services	None	Collection stations and marketing of grains, legal support	Fertilizer production, transports, wet processing of coffee	Legal assistance available via second level cooperative	None	None
Coffee extension per year	Monthly group trainings, (exporter)	Monthly group trainings	Monthly group trainings	Four group trainings and 3–6 farm visits	Six group trainings and monthly farm visits	Twenty group trainings and monthly farm visits
Extension-agent/ producer ratio	1/113	1/248	1/11	1/120	1/28	1/28
Financing of extension	Government institute	NGO	Self-financed and NGO	NGO	NGO, government institute	NGO, government institute
Coffee contracts with members	No, only via credit	No	No, only via credit	No, only via credit	No, only via credit	No, only via credit
Cooperative growth strategy	Stability in members, production and sales	Slower growth of members; stability in production and sales	Growth of cooperative, coffee production and sales	Growth of coffee production and sales	Growth of coffee production and sales	Growth of cooperative, coffee production and sales
Major income of cooperative	Through loan interests	Through loan interests	Coffee sales	Coffee sales	Coffee sales	Coffee sales
Profits available	No	Yes	Yes, but small	Yes	Yes	Yes
Reserve fund	Yes	Yes	No	Yes, small	Yes, very small	Yes
Credits obtained from...	Exporter	International (ethical) banks	Exporter	Second-level cooperative	Exporter	International (ethical) banks
Sufficient credit funds	No	Yes	No	Lack US$500,000	(Yes) Insufficient for member credits	Lack around US $250,000

normal which helps to increase their yield levels (see Table 5). The same cooperative also built a central wet processing station in 2006. This was an essential upgrading strategy as many individual members did not own wet processing mills.

The extension service for coffee producers varies significantly between cooperatives. The least favorable extension agent–producer ratio was offered by cooperative CONV-B/ORG-B for both their conventional and organic members (Table 2). The best extension agent–producer ratio is offered by the two smaller Organic-Fairtrade certified cooperatives that received funding from both an NGO and a governmental institution for their extension service. There is a tendency for certified cooperatives to offer a better extension agent–producer ratio compared with conventional cooperatives. As cooperative ORG-C could not obtain sufficient external funding for an extension agent, the members decided to pay part of it themselves.

Coffee producers do not have contracts regarding coffee delivery or prices with their cooperative. Except in cooperative CONV-B, members are obliged to pay back credits from the cooperative with coffee. Through this tied contract the cooperatives ensure loan repayment and coffee delivery. They can also estimate the minimum coffee quantity delivered to the cooperative which reduces the risk when negotiating with coffee buyers. As the conventional cooperatives have a stronger focus on offering financial services, they are able to provide sufficient credit to their members. The certified cooperatives have to limit their credit offer to their members because the cooperatives lack sufficient funds and face liquidity constraints. The conventional cooperatives finance themselves through loan interest, the certified cooperatives from coffee sales.

The certified cooperatives focus on growth of coffee production and thus coffee sales, with the aim of reducing transaction costs through economies of scale. The two conventional cooperatives focus on stability in production and sales. Cooperative CONV-B experienced strong member growth rates in the past 5 years; in 2003, they had only around 1400 members compared with 9300 in 2008. Apart from having opened many regional branch offices which contributed to their growth, the cooperative also introduced an insurance policy to cover funeral costs for their members, which according to informal statements, attracted many new members.

The cooperatives are not financially autonomous. Apart from cooperative CONV-B, all depend on credit and face limited credit access. Cooperatives often lack appropriate collateral and therefore do not obtain sufficient credit to manage satisfactorily the coffee marketing, investments or the members' credit demand. Cooperatives have no access to state bank credit which could help to reduce their dependency on exporters and international finance institutions. Cooperatives CONV-B/ORG-B and OFT-F obtain credit from international ethically oriented finance institutions such as Oikocredit or Rabobank. In the case of profits, credit access and reserve funds, no major differences can be identified between the conventional and certified cooperatives. Since 2004 cooperatives have been required by law to have a reserve fund to increase their financial stability, but cooperatives have struggled to build up this fund.

The business models of each cooperative differ and no major similarities can be found within each group of cooperatives apart from the certification strategy. When the organic and Organic-Fairtrade certified cooperatives are grouped, they have more aspects in common as a 'certified' group than with the conventional cooperatives. The certified cooperatives focus more on coffee-related services, while conventional cooperatives tend to have a stronger focus on financial services which may relate to their history.

Upgrading Strategies and the SWOT of Cooperatives

Analyzing the upgrading strategies and the SWOT of cooperatives, we found that while upgrading strategies are specific to each cooperative, the SWOT of cooperatives can be cooperative specific but some are also shared by all cooperatives. Since the SWOT of each cooperative are also linked to the upgrading strategies chosen, we have divided this section into a discussion of (i) the cooperatives' specific upgrading strategies and SWOT, and (ii) the SWOT which all cooperatives have in common.

Cooperative-specific upgrading strategies and SWOT

The upgrading strategies and SWOT of each cooperative are described in Tables 3 and 4, respectively. Based on these two tables, we analyze whether the upgrading strategies and individual SWOT are typical for and can, thus, be grouped according to conventional, organic and Organic-Fairtrade certified cooperatives.

The sampled cooperatives apply several upgrading strategies in order to improve the income of the cooperative and its members (see Table 3). The participating cooperatives concentrate on product, process, volume and functional upgrades, as well as vertical coordination. Product upgrades are similar between all cooperatives; the focus is on certification, distinct quality profiles and improved production, harvesting and processing. Process upgrades such as offering organic fertilizer, improved invoicing and services to coffee buyers or traceability are specific to only one cooperative. When the certified cooperatives are grouped together, they tend to offer more with regard to process upgrade than the conventional cooperatives. Nearly all cooperatives try to increase the coffee volume sold.

Table 3. Upgrading strategies of conventional, organic and Organic-Fairtrade certified cooperative models.

Cooperative	CONV-A	CONV-B/ORG-B	ORG-C	OFT-D	OFT-E	OFT-F
(1) Improvement of the product, production process or volume	**Product upgrade**					
	• Certification is planned • Quality project is planned • Improved production, harvest	• Organic production • Distinct quality profiles • Further certifications are planned	• Organic production • High quality • Improved production, harvest, processing	• Organic production • Fairtrade certification • Distinct quality profiles • Improved production, harvest, processing	• Organic production • Fairtrade certification • High quality • Improved production, harvest, processing	• Organic production • Fairtrade certification • Distinct and high quality profiles • Improved production, harvest, processing
	Process upgrade					
	• n.a.	• n.a.	• Improved production efficiency as own fertilizer production • Organic waste recycling into fertilizer	• n.a.	• Improved invoicing for producers	• Improved services for coffee buyers through side office • Traceability of coffee
	Volume upgrade					
	• No	• Yes	• No	• Yes	• Yes	• Yes
(2) Change and/or the adding of functions	**Functional upgrade**					
	• Commercial credits	• Input supply • Own dry mill • Own roasting and own local brand • Commercial credits • Agricultural diversification • Funeral insurance	• Input supply • Own wet mill • Own roasting and local brand (youth activity)	• Input supply • Cupping laboratory • Own dry mill • Own roasting and own local brand • (Limited) agricultural diversification • Ecotourism	• Input supply • Own local brand	• Input supply • Cupping laboratory • Own dry mill
(3) Value chain coordination	**Vertical coordination**					
	• Only with exporter	• Yes. Improved marketing through second-level cooperative	• Yes, starting. Improved marketing through alliances	• Marketing with second-level cooperative, direct contacts to roaster	• Yes, direct contacts to coffee importers/roasters	• Yes, direct contacts to coffee importers/roasters
	Horizontal coordination					
	• n.a.	• n.a.	• n.a.	• n.a.	• n.a.	• Planned transport alliance with other cooperatives to reduce costs

The range of functional upgrades is diverse and the number of upgrades in this category varies between the cooperatives. All cooperatives applied at least one functional upgrade, others up to six; yet, as Table 4 shows, with different levels of success. Comparing conventional, organic and Organic-Fairtrade certified cooperatives, no specific differences in upgrading strategies can be identified which go beyond the certification strategy and would allow for generalizations. This can be explained by the tendency of cooperatives to imitate the upgrading strategies of other cooperatives in the region. Also NGOs, including those linked to the government, advocate similar strategies for cooperatives.

The cooperative specific strengths vary between the cooperatives and range from good relationships to buyers and members, transparency, staff commitment to good coffee quality, to additional services offered. In terms of weaknesses we again found a large variance between the cooperatives, starting from the lack of a business plan, lack of sufficient credit access, lack of qualified or committed staff, low levels of extension, bad infrastructure, or implementation of too many upgrading strategies. The interviewed cooperatives plan to invest in increasing upgrading activities even though the potential benefits of this upgrading are not necessarily evaluated *ex-ante*. For example, upgrading strategies of cooperative OFT-D became a large financial and management burden for the cooperative and present a current weakness that is likely to turn into a threat.

Opportunities exist in finding new marketing alliances, improving coffee quality and yield levels, and increasing extension services and transparency. Other opportunities include more horizontal or vertical coordination for marketing (CONV-A, ORG-C and OFT-F) or respectively to downgrade (OFT-D). The planned change in horizontal value chain coordination of cooperative OFT-F to reduce export-related transport costs through a transport alliance with other cooperatives could be an opportunity for all certified cooperatives if it is well managed and regulated. Threats can range from the strong dependence on one buyer and on external financing of extension, to land constraints and cooperative debts. A threat mentioned especially by the Organic-Fairtrade certified cooperatives is the intense competition from other coffee buyers such as intermediaries, exporters and sometimes even other cooperatives. The usual advantage of non-cooperative buyers in Nicaragua is that they possess sufficient funds to pay producers on the spot and thus cash-desperate members sell their coffee to them.

The certified cooperatives are further threatened by high conventional coffee prices. This is because additional premiums for certified coffees dwindle as conventional coffee prices rise at a faster rate than organic and Fairtrade coffee prices. Since high-quality certified coffee is costly to produce, decreasing profit margins trigger an increase in low-quality coffee off-sales by the cooperative members. As the CEO of cooperative OFT-F puts it 'It sounds like a paradox, but the biggest threat for us is high world market coffee prices' (personal communication, April 2008).

Four lessons can be derived. First, apart from the certification strategy, it is difficult to further classify the cooperatives' upgrading strategies and SWOT into typical categories that only apply to conventional or only to organic or Organic-Fairtrade certified cooperatives. Second, successful upgrading strategies of one cooperative are copied by other cooperatives as most upgrading strategies are relatively easy to imitate. This creates competition in what are often very small market niches, such as certified coffees. Due to the limited market size for certified coffees, profit margins decrease as new cooperatives enter certification—even when certification costs decrease. Coffee buyers can exert more bargaining power and pressure on certified coffee prices (cf. conceptual framework). Certified cooperative managers, for example, stated in the interviews that organic premiums were declining, whereas buyers increasingly demand higher quality.

The third lesson is that activities and strategies which are strength for one cooperative can be a weakness or threat to another cooperative. This is the case for the cooperative's internal organization, staff commitment, the extension system and some upgrading strategies. A fourth lesson is that imitating an upgrading strategy is not always successful. This highlights the need for a careful choice of the upgrading strategy according to the cooperative business model.

SWOT common to all sampled cooperatives

Common strengths. The strength of all cooperatives is that coffee production is located at high altitudes with very good coffee quality potential. The region's coffee has won several prizes in highly prestigious international competitions. Generally, all cooperatives indicate a trend in the coffee industry towards higher quality, especially those having certification. Therefore, investing in high quality constitutes an opportunity for coffee growers and cooperatives of that region.

Common weaknesses. All cooperatives strongly depend on external credit supply and do not have enough own funds to run their operations. Not all have sufficient credit access to fully finance their operations or to offer adequate credit to their members. As cooperatives cannot provide enough credit, their members obtain additional credit from other sources, such as microfinance institutions, or from intermediaries who offer a cash advance on coffee delivered later. The coffee delivered to intermediaries is then not available to the cooperative, which reduces its turnover.

The cooperatives are located in an area with a weak rural infrastructure. This raises the cooperative's operation costs, e.g., expenses for an electrical generator,

Table 4. SWOT of conventional, organic and Organic-Fairtrade certified cooperative business models.

	Strengths	Weaknesses	Opportunities	Threats
CONV-A	• Mainly cost-recovering interest rates • Good treatment of members • Good relationship with exporter • Committed manager	• No business plan • Insufficient coffee commercialization service • External credit supply insufficient • Uncommitted field staff	• Improving coffee quality • Increase extension • Improve leadership of manager • Find new coffee marketing alliances • More vertical and horizontal coordination	• Strong competition from other cooperatives/ intermediaries buying coffee → contract breach with exporter • Dependence on exporter • Uncertainty about cooperative benefits
CONV-B / ORG-B	• Many services, including radio channel and shop • Mainly cost-recovering interest rates • Good coordination between administration/field staff • Good organizational model, good commitment • Good organic coffee quality • Internet access at all times • Good credit access → international ethical banks	• Strong growth in members → members loose identification with cooperative • Support for organic producers very low → dissatisfaction with cooperative and farming method • Insufficient extensionists and support for coffee producers	• Built up of strong extension system for their agricultural producers • Restructure toward more small-sized groups with regular meetings • Improve organic yields	• Not up-keeping with their services due to fast growth • Strong focus on financial services → competition from other microfinance institutions
ORG-C	• Strong support of members in case of problems • Own fertilizer production and transport to farmers • Strong cooperative values of leaders and members → high commitment and good treatment • High coffee quality • Alliance with exporter who offers good prices • Only weak competition from other coffee buyers • Management done by members themselves • Good extension services	• No skilled financing/marketing person • Limited marketing knowledge • No business plan • Bad infrastructure (e.g., no phone, internet, electricity, administration by hand) • No own vehicle or truck • Credit supply insufficient to finance producers	• Get high quality better rewarded through additional market alliances • Coffee quality tests to increase bargaining possibility with exporter • Increase higher education in financing/marketing of responsible cooperative members • Open a mini office in a nearby village with infrastructure	• Coffee price volatility • Strong dependence on exporter • Land constraints and high poverty among members → neglect coffee fields in search for additional income opportunities • Problems with obtaining land title for the cooperative's members
OFT-D	• Coffee sorted according to quality • Good support by buyers • Good 'self-marketing' skills • Internet access in office • Own coffee brand • Offer different production technologies	• Unmotivated extensionists • Financial mismanagement → debts • Low coffee prices paid to producers • Internal organizational model problematic • Too many non-beneficial upgrading strategies • Oversized investments	• Increase extension agent-producer ratio • Improve coffee yields • Increase transparency and payment schemes to producers • Downgrade in functions • Restructure internal organization in smaller groups	• Members dissatisfaction with organic farming and prices → contract non-compliance • Loss of certification • Further indebtedness

OFT-E	• Good prices for producers and price premiums • Good quality • High transparency in producer bills • Basic organic input provision • One very committed head of extension agents and good extension services	• Difficulties for buyers to contact cooperative → slow responding of e-mails • Internal staff problems • Insufficient credit possibilities for producers • High processing and export costs • Cannot offer good spot market prices	• Ally with other cooperatives to lower transport and marketing costs • Change subcontracted dry mill • Stronger internal management/leadership	• Dependence of external financing of extension • High world market prices → off-sales → no contract compliance • Loss of committed staff
OFT-F	• Very committed, producers and cooperative staff • Transparency in their activities • High quality of coffee → strong quality controls • Second office in other city → good contact with buyers • Cooperative staff are often members themselves • Support of producers in case of emergency • Strong efforts to increase producer revenues → good extension services	• Coffee commercialization costs are high, especially transport costs to harbor • Low yields despite many efforts from cooperative • Credit supply insufficient as collateral lacks • Demand for high quality raises costs for producers	• Ally with other cooperatives regarding transport to lower commercialization costs • Extend cupping laboratory • Enter more the gourmet quality market • Stronger focus on replanting/improving coffee plantations • Improve yields	• Dependence on external financing of extension • High world market prices → off-sales → no contract compliance → loss of buyers

transport problems due to unpaved roads and bad condition, unreliable fixed phone, poor mobile phone and Internet connectivity. None of the cooperatives have completely self-financed extension service and they depend strongly on externally funded extension provision which is often tied to short-duration development projects.

Common threats. A threat for cooperatives is the microclimatic variation. Coffee producers and cooperatives indicated that weather conditions are becoming less predictable, whereas coffee requires a specific rainfall pattern over the year. The microclimatic variations make it difficult for cooperatives to estimate accurately the harvest, hence, threatening compliance with coffee and credit contracts, and increasing transaction costs. A further threat is the possibility of corruption and mismanagement of cooperative funds as members have little control over the decisions taken by the board of executive managers.

Common opportunities. To increase members' control over management and to make the benefits of the cooperative more visible, one possible solution is to develop and implement the concept of a member's promotion plan. The plan with verifiable goals should be provided at the beginning of the business year and evaluated at the annual assembly. Additionally, there could be an annual record of each member's cumulative capital contributions (e.g., the association fee or the percent retained from credits for reserve funds) and some sort of share certificate acknowledging the members' contribution.

Another opportunity is to increase transparency by specifying the deductions on the coffee price, e.g., processing and certifications, in the final bill for the delivered coffee. Credit repayments should be issued on a separate invoice. Although this involves human and financial resources, these documents enhance transparency and could increase members' loyalty and satisfaction. It would also enable members to make more informed decisions about membership, upgrading of production systems, certification and marketing.

Linking Coffee Gross Margins to Cooperative Business Models, Certification and Upgrading Strategies

The average yield levels and gross margins of coffee producers are shown in Table 5. The members of the two conventional cooperatives received on average a similar coffee price across all market channels (2.08–2.12US $/kg). Cooperative CONV-B paid its members with 2.19US$/kg significantly higher maximum coffee prices than the exporter of CONV-A (2.06US$/kg). The yield level is 18% higher in cooperative CONV-B and since production costs per hectare are similar between the two conventional cooperatives, this results in a 90US$/ha higher gross margin for producers in CONV-B compared with CONV-A.

Between the two organic-certified cooperatives there is a high variation in yield. The yield per hectare of cooperative ORG-B is nearly half compared with ORG-C (293 kg/ha compared with 516 kg/ha, respectively). The average coffee prices producers obtained across all market channels are similar between the two cooperatives, but cooperative ORG-C paid significantly higher maximum coffee prices to its members although the absolute difference is only 0.06US$/kg or 2%. Although producers of ORG-C have higher variable production costs, their gross margins are still double that of ORG-B. Some reasons behind the significantly higher yield of cooperative ORG-C's coffee producers are better management of their coffee plantations and good access to organic fertilizer.

The members of the Organic-Fairtrade certified cooperatives have similar yield ranges as cooperatives ORG-B, CONV-A and CONV-B. However, there are differences in yield levels, coffee prices and production costs among the Organic-Fairtrade certified cooperatives. Members of the cooperative OFT-D have only slightly higher average coffee prices as producers in the conventional cooperatives, whereas the other Organic-Fairtrade producers obtain better average prices (10–14% higher). The highest prices paid by the cooperatives are almost similar among all three Organic-Fairtrade cooperatives (2.39–2.47US$/kg). A possible explanation is that members of cooperative OFT-D either had higher off-sales than the other cooperative members or opted more frequently for spot market prices instead of waiting for the final bill several months later.

Yield levels and production costs are relatively similar between cooperative OFT-D and OFT-F, whereas members of cooperative OFT-E have 34–40% higher yields and 22–38% higher production costs. With the higher yields, members of OFT-E have, despite higher production costs, the highest gross margins, earning 62% more than members of cooperative OFT-D. Members of OFT-D obtained the lowest per hectare gross margins of all the cooperatives. Its members also showed dissatisfaction with the organic farming system and their cooperative during the interviews. The low coffee prices and low gross margins in OFT-D reflect management problems, failing upgrading strategies and the weaknesses of the cooperative. Although members in the other Organic-Fairtrade cooperative, OFT-F, received only 40US$/ha more, they were satisfied with the prices, their cooperative and its services. The farmers of OFT-F mentioned low yields, caused by old and low-density planted plots, as their major problem. They aim to improve their plots, but lack credit for long-term investments such as the replanting of coffee.

The highest gross margin of US$904 is obtained by the organic cooperative ORG-C followed by the Organic-Fairtrade certified cooperative OFT-E (US$629).

Table 5. Coffee prices (US$/kg) and gross margins per hectare coffee of conventional, organic and Organic-Fairtrade certified cooperatives.

Cooperative	CONV-A	CONV -B	ORG-B	ORG -C	OFT-D	OFT-E	OFT-F
	Means ± SD						
Yield of green coffee (kg/ha)	333.0 ± 180.7	393.6 ± 200.1	293.1[a] ± 223.7	515.8[a] ± 235.0	292.3 ± 106.5	411.2 ± 200.9	306.2 ± 148.3
Average farm-gate coffee price (US$/kg)	2.08 ± 0.2	2.12 ± 0.27	2.29 ± 0.15	2.28 ± 0.2	2.14 ± 0.46	2.38 ± 0.16	2.35 ± 0.26
Highest farm-gate coffee price paid by the members' cooperative (US$/kg)	2.06[a] ± 0.19	2.19[a] ± 0.13	2.31[a] ± 0.13	2.37[a] ± 0.11	2.39 ± 0.12	2.42 ± 0.16	2.47 ± 0.23
Revenue (US$/ha)	693.1 ± 372.8	821.3 ± 409.5	666.9[a] ± 503.7	172.5[a] ± 555.7	639.4[a] ± 297.2	975.5[a,b] ± 464.6	711.9[b] ± 338.9
Variable production costs (US$/ha)	238.9 ± 180.6	275.4 ± 139.4	205.1 ± 130.1	268.3 ± 231.1	251.3 ± 203.6	346.6 ± 272.1	283.4 ± 212.1
Gross margin (US$/ha)	454.2 ± 320.9	545.9 ± 371.5	461.8[a] ± 437.6	904.2[a] ± 487.5	388.1[a] ± 278.2	628.9[a] ± 346.4	428.5 ± 276.0

[a] Significant difference at $P < 0.01$.
[b] Significant difference at $P < 0.05$.
Superscript letters indicate a significant difference between two groups marked by the same number. Prices and gross margins statistically compared within a certification status, i.e., between CONV-A and CONV-B, between ORG-B and ORG-C, and between OFT-D, OFT-E and OFT-F. All variables were non-normally distributed. Kruskal–Wallis tests were used to test for statistical differences, followed by pairwise comparisons based on the Mann Whitney *post hoc* test adjusted by the Bonferroni correction factor where applicable[61].

Paradoxically, the two lowest gross margins of US$388 and US$429 are also obtained by Organic-Fairtrade certified cooperatives (OFT-D and OFT-F). Members of conventional cooperatives have gross margins somewhere between those of the certified cooperatives.

Table 6 ranks the cooperatives according to the gross margins earned by the cooperative members, by the cooperatives' business models, and upgrading strategies. There is no obvious association between the certification strategy of a cooperative and the gross margins producers obtain. Producers in certified cooperatives may have either higher or lower gross margins than producers in conventional cooperatives. Members' satisfaction as well as the net of strengths and weaknesses of a cooperative can be related to the gross margin. The data indicate that OFT-F is an exception. It is a very well-run and organized cooperative, but has very low gross margins for members. The example of the cooperative ORG-C shows that its many weaknesses can be compensated by its strengths and coffee-related services, resulting in high member satisfaction and contributing to good gross margins. The number and importance of strengths and weaknesses as well as the amount of coffee-related services offered to producers seem to affect the gross margins more than certification. Table 6 also shows no clear relationship between the certification strategy of a cooperative and the number of other upgrading strategies, cooperative size and financial characteristics. This qualitative evaluation indicates that the gross margins per hectare depend more on yield levels, the business model of a cooperative, its respective SWOT and upgrading strategies than on certification *per se*.

Conclusion

In this paper, we analyzed the business models, upgrading strategies and SWOT of coffee cooperatives in northern Nicaragua and linked these to members' coffee gross margins. Since the business models of each cooperative differ, it is not possible to differentiate according to typical characteristics of conventional, organic and Organic-Fairtrade certified cooperatives. Yet, as a group, the certified cooperatives have a stronger focus on coffee-service provision, such as coffee marketing, input supply and extension, than on financial services such as the conventional cooperatives. These differences cannot be generalized beyond the research region due to the sampling framework, but merit further research.

Cooperatives often choose the same upgrading strategies as other cooperatives. Hence, apart from the certification, upgrading strategies are not typical for one group, be it conventional, organic or Organic-Fairtrade certified cooperatives. The cooperatives' SWOT is related to the cooperative's business model and the specific upgrading strategies undertaken. Again, there is not much common ground in each of the three groups of

Table 6. Relative ranking of conventional, organic and Organic-Fairtrade certified cooperatives.

	CONV-A	CONV-B/ORG-B	ORG-C	OFT-D	OFT-E	OFT-F
Average gross margins	**Middle**	**Middle**	**High**	**Low**	**High**	**Low**
Upgrading						
Certification as upgrading strategy	n.a.	n.a./Organic	Organic	Organic-Fairtrade	Organic-Fairtrade	Organic-Fairtrade
Number of other upgrading strategies	Low	High	Middle	High	High	High
(a) Coffee-related services offered	(a) Very few	(a) Few	(a) Many	(a) Many	(a) Many	(a) Many
(b) Quality of these services	(b) Basic	(b) Medium	(b) Very good	(b) Low	(b) Very good	(b) Very good
Business model						
Size of cooperative	Middle	Large/small	Small	Large	Middle	Small
Financial situation and characteristics of cooperative	Middle	Very good	Weak	Weak	Good	Good
Number and importance of strengths	Few	Middle	Many	Few	Middle-many	Many
Number and importance of weaknesses	Middle	Middle/many	Middle	Many	Few	Few
Members' satisfaction and commitment to cooperative[1]	Low	Low	High	Low	Middle	High

[1] Only indirectly measured, based on qualitative interviews, informal comments and observations. ORG-C and OFT-F offer many 'informal services' such as helping members incapable of paying their debts, providing transport to hospital, granting collateral-free credit in case of severe illness/accident, etc.

conventional, organic and Organic-Fairtrade certified cooperatives. The lack of clear differences between the groups of cooperatives is noteworthy. It is probably due to the growing popularity of environmental and social certification, as well as the imitation of other upgrading strategies without proper evaluations of their appropriateness to the cooperative in question.

We found no obvious association between a cooperative's certification strategy and the gross margins to its members. The number and importance of strengths and weaknesses, as well as the amount of coffee-related services offered to producers tend to be more related to gross margins than due to organic or Organic-Fairtrade certification *per se*. Based on a qualitative evaluation, we conclude that the gross margins depend on yield levels, the cooperative's business model (and the services it offers its member), its respective SWOT and its upgrading strategies, of which certification is but one. Coffee certification is not always the solution to increase smallholder coffee incomes but may serve as a buffer in case of extremely low coffee prices. Cooperatives need to identify specific upgrading strategies and market niches which do not overburden the cooperative's management or finances; thus which are in line with the cooperative's business model.

To be a successful upgrading strategy, organic or Organic-Fairtrade certification strongly depends upon the business model of a cooperative, its strengths, weaknesses and other supportive upgrading strategies. Future research needs to be based on quantitative assessments of the impacts of certification schemes on the socioeconomic effects on smallholders. Such assessments should include the institutional context in which farmers operate through explicitly analyzing conventional and certified cooperatives' business models, their upgrading strategies and SWOT. When evaluating only one upgrading strategy such as certification, researchers are likely to miss the real effect if the business models, other upgrading strategies and SWOT are not taken into account and controlled for in the analysis.

The following presents policy recommendations that can address the SWOT common to all cooperatives; the individual SWOT is easier to be addressed by the cooperative management. Policies that aim at increasing smallholder coffee incomes through upgrading should focus, apart from production aspects, on the institutional context of smallholders and their cooperatives. Regarding coffee production, the low yield levels as well as the climatic risks need to be addressed—for example through a successive switch to higher yielding, less climate-susceptible coffee varieties, improved shade management in the coffee plantation or by even diversifying into other agricultural crops. Research needs to identify appropriate coffee varieties and also alternative crops for these higher regions. To ensure extension services in the long run, it is recommended that cooperatives oblige producers to participate in financing the extension service.

Institutional support at the national level is also of great importance. Until 2008, Nicaraguan governmental

support to cooperatives, agricultural producers and coffee smallholders was negligible. At the same time, producers from other coffee producing countries such as Colombia, Costa Rica, Brazil or Mexico count on governmental sector strategies and support, not only through credit, extension, subsidies, market support or infrastructure, but also through research and generally higher educational levels. The absence of this support in Nicaragua and the lack of a functioning national coffee institution, make it difficult for Nicaragua's coffee growers to compete internationally. Coffee certification alone cannot improve producers' welfare in the long run because newly certified producers will erode profit margins for all.

Enforced by policies or voluntarily, cooperatives could be more transparent in their invoices and issue a record of each member's cumulative capital contributions or share certificates acknowledging the member's role in the cooperative. Policies could address the liquidity constraints of cooperatives through, for example, a supportive national banking system or an agricultural bank that provides business credits at market interest rates to the cooperatives. Additionally, policies could promote a diversified microfinance sector to serve the cooperatives' members. Microfinance institutions could provide short-term consumption credits to producers during harvest time to reduce their need for spot market sales.

Credit for coffee carries excessive covariate risk with respect to yields, climate, prices and competition. Such risk can be better shouldered by international finance institutions or by broadly diversified, national microfinance and banking institutions[62]. Such institutions could provide credit to the cooperative's members, whereas the cooperative sells the member's coffee and then first pays the member's credit at the microfinance/banking institution before paying the remaining gains from coffee sales to the credit-using member. As the cooperatives themselves could undertake the screening, monitoring and loan enforcement functions, microfinance institutions could serve them at relatively low transaction costs. By building up more equity capital and their reserve fund, cooperatives can improve their liquidity position and credit worthiness over time. This process should be made transparent so that members are aware that their shares in their cooperative are increasing. The introduction of an obligatory annual external auditing of first-level and second-level cooperatives is recommended to avoid mismanagement and corruption, and to make cooperatives more creditworthy for banks. A coffee institute could then also become responsible for the monitoring of finances or the auditing of cooperatives and could forge links with the national banking system and international banks.

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Contribution and assessment of recycled menthol mint vermicompost on productivity and soil quality in mint and mint–rice–wheat rotation: A case study

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Abstract

Trials in farmers' field(s) were conducted to study the usefulness of vermicompost (VC) produced from distillation waste of menthol mint (*Mentha arvensis* L. cv. Kushal) using earthworms (*Eisenia foetida*) in reducing the inputs of chemical fertilizers and improving soil health in menthol mint-based cropping systems. Results of the first trial conducted on menthol mint (sole crop) in the fields of 45 farmers clearly indicated that 75% of the chemical fertilizer inputs can be reduced by supplementing the fields with 5 t ha^{-1} of menthol mint VC leading to higher levels of profits to the farmers by significantly improving herb and oil yield (6.7 and 8.4%, respectively) compared to the full recommended dose of chemical fertilizers (NPK 75:60:60 kg ha^{-1}). The second trial was conducted in the fields of six farmers adopting a menthol mint cropping system (mint–rice–wheat–mint) where significantly higher yields were recorded in plots supplemented with 5 t ha^{-1} of menthol mint VC + 25% of the recommended dose of chemical fertilizers; an increase of 5.6–7.2% in mint oil and 6.6% in wheat yield over the plots receiving the full recommended dose of chemical fertilizers (NPK 75:60:60 kg ha^{-1}). However, in the case of rice, the highest grain yield was observed within plots receiving the full recommended dose of chemical fertilizers. Data obtained on soil properties clearly showed that apart from enhancing the yields of crops, the integration of VC with chemical fertilizers considerably improved the soil fertility/sustainability status in terms of organic carbon, available N, P and K.

Key words: vermicompost, mint–rice–wheat rotation, crop yield, soil quality

Introduction

In the post green revolution era, the growth and yield of many crops have started declining in spite of continuous development of improved varieties and technologies. This has been attributed to poor soil management particularly with regard to no or negligible use of organic manures in crop cultivation, leading to development of macro- and micro-nutrient deficiencies under intensive cropping. The faulty practice of solely depending on the major nutrients (N, P and K) and over mining of all the essential nutrients has further aggravated the problem. The unique advantage with organic manure (farm yard manure (FYM), compost and green manuring) is that besides supplying major as well as trace elements, it improves the physical and biological properties of the soil. On the other hand, besides their difficult availability, higher cost and being manufactured from non-renewable energy sources, inorganic fertilizers are potent agents for polluting the environment and contaminating ground water. The basic problem with organic manure is that the nutrients supplied through them are not sufficient to sustain the productivity of high-yielding food and other crops. The best proposition, therefore, is to manage the crop with a judicious combination of organic and inorganic source of plant nutrients, putting less emphasis on expensive synthetic inorganic fertilizer[1].

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Table 1. Characteristics of VC produced from *M. arvensis*.

Nitrogen ($g\,kg^{-1}$)	15–18
Phosphorus ($g\,kg^{-1}$)	9–10
OC ($g\,kg^{-1}$)	160–165
pH	7.1
Zinc ($mg\,kg^{-1}$)	200–250
Iron ($mg\,kg^{-1}$)	350–450
Manganese ($mg\,kg^{-1}$)	200–225
Copper ($mg\,kg^{-1}$)	47–53

OC, organic carbon.

Vermicomposting has been recognized as an efficient, environment friendly technology for converting organic waste into high-value organic manure[2,3]. Distillation wastes (after extraction of essential oils) of many aromatic crops retain their nutritional values and may be recycled directly or after vermicomposting[4] to supplement both the major and minor nutrient requirements of the crop(s)[1]. Chemical fertilizers together with available quantity of organic manure/compost are now commonly used to sustain soil fertility and attain the desired level of yield of high-value essential oil-bearing crop[5].

In the past few decades, the economics of rice–wheat rotation has turned less attractive, and diverse crop rotations with rice, involving seasonal vegetables and menthol mint have become popular. A recent survey showed that in the indo-Gangatic plains, rice remains the principal kharif crop, occupying about 76% of land. In the rice-cropped area, rabi grains occupied only about 70% of land; mint and vegetables occupied the rest of the land. The conventional rice–wheat rotation has now been replaced by rice–wheat–mint rotation after release of short-duration varieties of menthol mint, resulting in larger profits to the farmers from a unit area.

The present study was conducted in farmers' fields in the existing *Mentha*-based cropping system with an objective to elucidate the extent of chemical fertilizers that can be avoided by supplementing the nutritional requirement of the crop with vermicompost (VC) produced from the distillation waste of *Mentha arvensis vis-à-vis* its effect on productivity and soil quality in mint and mint–rice–wheat rotation.

Materials and Methods

Experimental sites

The experiments were conducted in selected farmers' fields belonging to nine villages (Safdarganj, Dalutpur, Dadra, Dhaurmau, Nargismau, Jamuvassi, Muzafarmau, Sarsuandhi, Ghorsara of districts Barabanki and Lucknow, Uttar Pradesh). Barabanki is located at 27°19′ to 26°30′ N and 80°05′ to 81°51′E, whereas Lucknow is located at 26°30′ to 27°10′ N and 80°30′ to 81°13′E and 123 m above mean sea level.

Production of quality VC

The Central Institute of Medicinal and Aromatic Plants (CIMAP) has developed a technology for production of quality VC utilizing distillation waste of aromatic crops[6,7]. VC was produced in the farmers' experimental sites (farmers owning distillation units and having sufficient quantities of mint distillation waste) of nine villages utilizing distillation waste of menthol mint and earthworm epigeic species *Eisenia foetida* in vermicomposting pits along with cow dung (6 m × 1.25 m × 0.5 m). Cow dung is added as a worm-bedding material together with the mint distillation waste. The substrate was turned-over every week to avoid a thermophilic stage. The pits were harvested after 12 weeks when the compost was ready by its physical appearance, as judged by development of a dark brown to black color with uniformly granular structure, and at this stage watering was stopped. Two days later, the compost was removed from the pits along with worms and uniformly spread on plastic sheets under shade. The harvested material was allowed to shade dry for 2 days to retain the moisture content of approximately 45 ± 2.0. VC was recovered after sieving (< 2 mm) the produced VC and the adult worms were separated and used in other pits for the same process. Samples were collected from sieved VC (about 50 g) for chemical analysis. The produced VC was used in the experimental trails. The chemical composition of VC used in the two trials conducted is given in Table 1.

Treatments and crop culture

The experimental field trials were conducted in a plot size of 5 m × 10 m with the following treatments:

T1 = Full recommended dose of chemical fertilizers N:P:K (75:60:60) $kg\,ha^{-1}$
T2 = VC ($2.5\,t\,ha^{-1}$) + 50% NPK
T3 = VC ($5\,t\,ha^{-1}$) + 25% NPK
T4 = VC alone ($7.5\,t\,ha^{-1}$).

The treatments were evaluated in two experiments. In the first experiment, a total of nine villages were involved and each village represented five farmers. The average data of each treatment of each village (pooled data of five farmers) were taken as a replication. The second experiment was also conducted during two cropping seasons. For the second experiment, six farmers were selected based on practicing a rice–wheat-mint cropping system. The four treatments (same as in experiment 1) were imposed on a plot area of $50\,m^2$ of each farmer. Six farmers represented replications. For the above experiments, nursery raised seedlings of menthol mint (cv. Kushal) were transplanted in the last week of March and the first week of April during each cropping season. In all the crops, weeding and intercultural operations were carried out as and when required. The treated plots were maintained with the same treatments for all the crops (mint–rice–wheat). The cultivars included in the present

Table 2. Effect of single and combined applications of inorganic fertilizer and VC on essential oil yield of *M. arvensis* cv. Kushal (Experiment 1).

Treatments	Herb yield ($t\,ha^{-1}$)[1]	Oil content (%)[1]	Oil yield ($kg\,ha^{-1}$)[1]
T1	17.71[a]	0.75[a]	133.80[a]
T2	18.14[ab]	0.73[a]	132.80[a]
T3	18.9[b]	0.76[a]	145.00[b]
T4	18.35[ab]	0.74[a]	137.24[a]
LSD ($P<0.05$)	0.82	NS	6.05

[1] Mean of nine observations for each treatment; values in vertical columns followed by different superscript letters are significantly different at $P<0.05$ by ANOVA (LSD) test. 100% NPK, 75:60:60 $kg\,ha^{-1}$; T1,100% NPK; T2, VC 2.5 $t\,ha^{-1}$ + 50% NPK; T3 = VC 5.0 $t\,ha^{-1}$ + 25% NPK; T4, VC 7.5 $t\,ha^{-1}$; VC, vermicompost; NS, non-significant differences.

study were 'Kushal' of menthol mint, Pusa-1 of rice and PWB 343 of wheat. The recommended doses of inorganic fertilizers were applied through urea, single super phosphate and muriate of potash at the rates of 75 kg N, 60 kg P and 60 kg K ha^{-1}, respectively.

Yield measurements

Above-ground foliage of the mint crop was harvested during the first fortnight of June. For determining essential oil content, extraction of oil was conducted with 200 g fresh herb following hydro-distillation using Clevenger's apparatus[8] for 4 h. The harvesting of rice and wheat was performed in the fortnight of October and the first week of April, respectively, in each cropping season.

Gas chromatography

Gas chromatography (GC) analyses of the oil samples were performed on a Perkin-Elmer Autosystem XL with FID attachment and a PE-5 column (30 m, 0.32 mm i.d., 0.25-μm film thickness), using hydrogen as the carrier gas at 6 psi inlet pressure. Injector and detector temperatures were 200 and 250°C, respectively. The column temperature was programmed from 60 to 230°C at 5°C min^{-1}, with initial and final temperature holds of 2 and 4 min, respectively. The data were processed on Turbo-Chrom Navigator software (Perkin-Elmer) for oil composition. Kováts RI software was used for the measurement of retention indices from FID data.

Economic analysis

Economic evaluation of fertilizers (NPK), VC and their combinations was made through net income (NI). For this, the cost of cultivation (CC) of mint–rice–wheat was calculated on the basis of different operations performed and materials used suckers, nursery preparation and maintenance of saplings, field preparation, transplanting, fertilizer application, irrigation, harvesting and

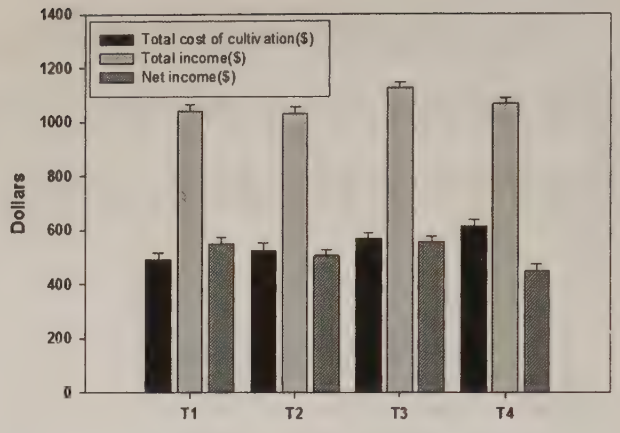

Figure 1. Economics of menthol mint cultivation (Experiment 1); vertical error bars indicate the standard error (SE); T1 = 100% NPK, T2 = 2.5 $t\,ha^{-1}$ VC + 50% NPK; T3 = 5.0 $t\,ha^{-1}$ VC + 25% NPK; T4 = 7.5 $t\,ha^{-1}$ VC; 100% NPK = 75:60:60 $kg\,ha^{-1}$; VC = vermicompost; 1$ = 45 INR.

Table 3. Major chemical properties of soil (pre-planting and post-harvest of *Mentha*) (Experiment 1).

Treatment	OC ($g\,kg^{-1}$)[1]	Available N ($kg\,ha^{-1}$)[1]	Available P ($kg\,ha^{-1}$)[1]	Available K ($kg\,ha^{-1}$)[1]
Pre-planting level	8.7	216.7	13.6	151.6
Post-harvest level				
T1	9.4[a]	236.5[a]	14.2[a]	171.0[b]
T2	10.4[b]	238.3[a]	15.6[b]	175.2[c]
T3	11.6[c]	250.2[b]	17.3[d]	182.7[d]
T4	11.7[c]	243.6[ab]	16.5[c]	167.6[a]
LSD ($P<0.05$)	0.6	7.03	0.65	2.21

[1] Mean of nine observations for each treatment; values in vertical columns followed by different superscript letters are significantly different at $P<0.05$ by ANOVA (LSD) test. 100% NPK, 75:60:60 $kg\,ha^{-1}$; T1, 100% NPK; T2, VC 2.5 $t\,ha^{-1}$ + 50% NPK; T3, VC 5.0 $t\,ha^{-1}$ + 25% NPK; T4, VC 7.5 $t\,ha^{-1}$; VC, vermicompost; OC, organic carbon.

distillation of essential oil. The expenditures for use of the different materials and operations performed were: mint suckers at \$0.78 kg^{-1}, nursery raising, field preparation and planting of mint sapling \$133.3 ha^{-1}, N \$0.14 kg^{-1}, P \$0.22 kg^{-1}, K \$0.34 kg^{-1}, VC \$0.022 kg^{-1}, irrigation \$2.22 $unit^{-1}$, per day labor charges \$1.67, essential oil distillation \$0.67 kg^{-1} fresh herb. Gross income (GI) was calculated by multiplying essential oil yield by oil price, that is \$7.78 kg^{-1}. Net income (NI) was calculated as = GI–CC.

Soil and VC analysis

In the beginning and at harvesting of each crop (mint and rice–wheat–mint cropping system), soil samples were collected using a soil auger from 0 to 15 cm depth at five places in the experimental field covering all treatments

Table 4. Correlation coefficients between soil parameters and essential oil yield in menthol mint (*M. arvensis*) crop cultivated in farmers' fields in the districts of Lucknow and Barabanki of Uttar Pradesh (Experiment 1).

	Correlation coefficients between soil and plant parameters					
Soil/plant parameters	**Available N ($kg\,ha^{-1}$)**	**Available P ($kg\,ha^{-1}$)**	**Available K ($kg\,ha^{-1}$)**	**Herb yield ($t\,ha^{-1}$)**	**Oil content (%)**	**Oil yield ($kg\,ha^{-1}$)**
Soil OC (%)	0.326**	0.594**	0.170*	0.242**	0.234**	0.594**
Available N ($kg\,ha^{-1}$)		0.00	0.244**	0.307**	0.421**	0.194**
Available P ($kg\,ha^{-1}$)			0.343**	0.282**	0.183*	0.311**
Available K ($kg\,ha^{-1}$)				0.443**	−0.238**	0.346**
Herb yield ($t\,ha^{-1}$)					0.221**	0.968**
Oil (%)						0.430**

* , ** Significant at 5 and 1%, respectively.
OC, organic carbon.

and replications. The collected soil samples were screened, pulverized using a wooden pestle and mortar, and passed through a 2-mm nylon mesh sieve. The physical and chemical analyses of soil/VC are presented on a dry weight basis. The processed samples were analyzed for organic carbon (OC) by the Walkley and Black method[9], available N by the alkaline $KMnO_4$ method[10], 0.5 M $NaHCO_3$ (pH 8.5) for extractable P[11] and 1 N NH_4OAc for extractable K[12].

The pH was measured in a 1:5 (w/v) suspension of VC with de-ionized water[13]. Total N was measured in oven-dried (60°C) samples by sulphuric acid digestion using selenium (Se), $CuSO_4$ and K_2SO_4 as the catalyst mixture and the regular Kjeldahl distillation method[14]. Total OC content was determined by the Walkley Black method[9]. One gram of material was dry-ashed at 550°C in a muffle furnace and the ash was extracted with 2 M HCl. The extract was analyzed for total P using the ascorbic acid method[15], total potassium by flame photometer[12] and total zinc (Zn), iron (Fe), manganese (Mn) and copper (Cu) by atomic absorption spectrometry[16].

Statistical analysis

Data on all observations were subjected to the analysis of variance (ANOVA) method and least significant difference (LSD) was calculated to determine the statistically significant treatment differences at the 5% level of significance for the error degree of freedom[17]. Linearity in associations between different yield and soil status/characteristics were observed using correlation coefficients (r) over the treatments. The standard error (SE) of the mean in vertical bar charts was computed with the help of Sigma Plot 10 (http://www.sigmaplot.com).

Results and Discussion

Experiment 1

Data collected on yield attributes of menthol mint in the experiment conducted in the fields of nine villages

Table 5. Effect of sole and combined application of inorganic fertilizers and VC on yield of different crops in the rotation (Experiment 2).

	Yield of			
Treatment	***Mentha* essential oil ($kg\,ha^{-1}$)^{1}**	**Rice grain ($t\,ha^{-1}$)^{1}**	**Wheat grain ($t\,ha^{-1}$)^{1}**	***Mentha* essential oil ($kg\,ha^{-1}$)^{1}**
T1	130.6^{a}	3.90^{c}	3.50^{b}	141.0^{a}
T2	133.0^{a}	3.16^{a}	3.30^{a}	146.0^{bc}
T3	142.0^{b}	3.18^{a}	3.73^{c}	149.0^{c}
T4	131.0^{a}	3.45^{b}	3.52^{b}	139.0^{a}
LSD ($P<0.05$)	3.48	0.14	0.12	3.35

^{1} Mean of six observations for each treatment; values in vertical columns followed by different superscript letters are significantly different at $P<0.05$ by ANOVA (LSD) test.
100% NPK, 75:60:60 $kg\,ha^{-1}$; T1, 100% NPK; T2, VC 2.5 $t\,ha^{-1}$ + 50% NPK; T3, VC 5.0 $t\,ha^{-1}$ + 25% NPK; T4, VC 7.5 $t\,ha^{-1}$; VC, vermicompost.

indicated that the percentage essential oil content (1.0 ± 0.1%) and oil quality (menthol: 80 ± 2.1%, neomenthol: 2.0 ± 0.8%, methyl acetate: 3.28 ± 0.11%, isomenthone: 3.2 ± 0.1%, menthone: 4.63 ± 0.12%) did not change significantly under different treatments; however, herb yield had a marginal response with application of VC in combination with inorganic fertilizer. Significantly higher herb yield (6.7%) was obtained with T3 over T1 (Table 2). As an organic fertilizer, VC from wastes of medicinal and aromatic crops has been shown to improve soil nutrient status and overall health[18]. The presence of nitrates and available forms of phosphorus, calcium and magnesium in VC[19] *vis-à-vis* the micronutrients might have favorably influenced the yields. Findings of the present study are similar to the previous studies showing improved plant growth and yield with the application of VC in other crops such as tomato[20]. Accordingly, the oil yield followed the same pattern as of herb yield with the decreasing order of T3 > T4 > T1 > T2 (Table 2). The application of VC produced from raw distillation waste has been observed to be a good source of organic

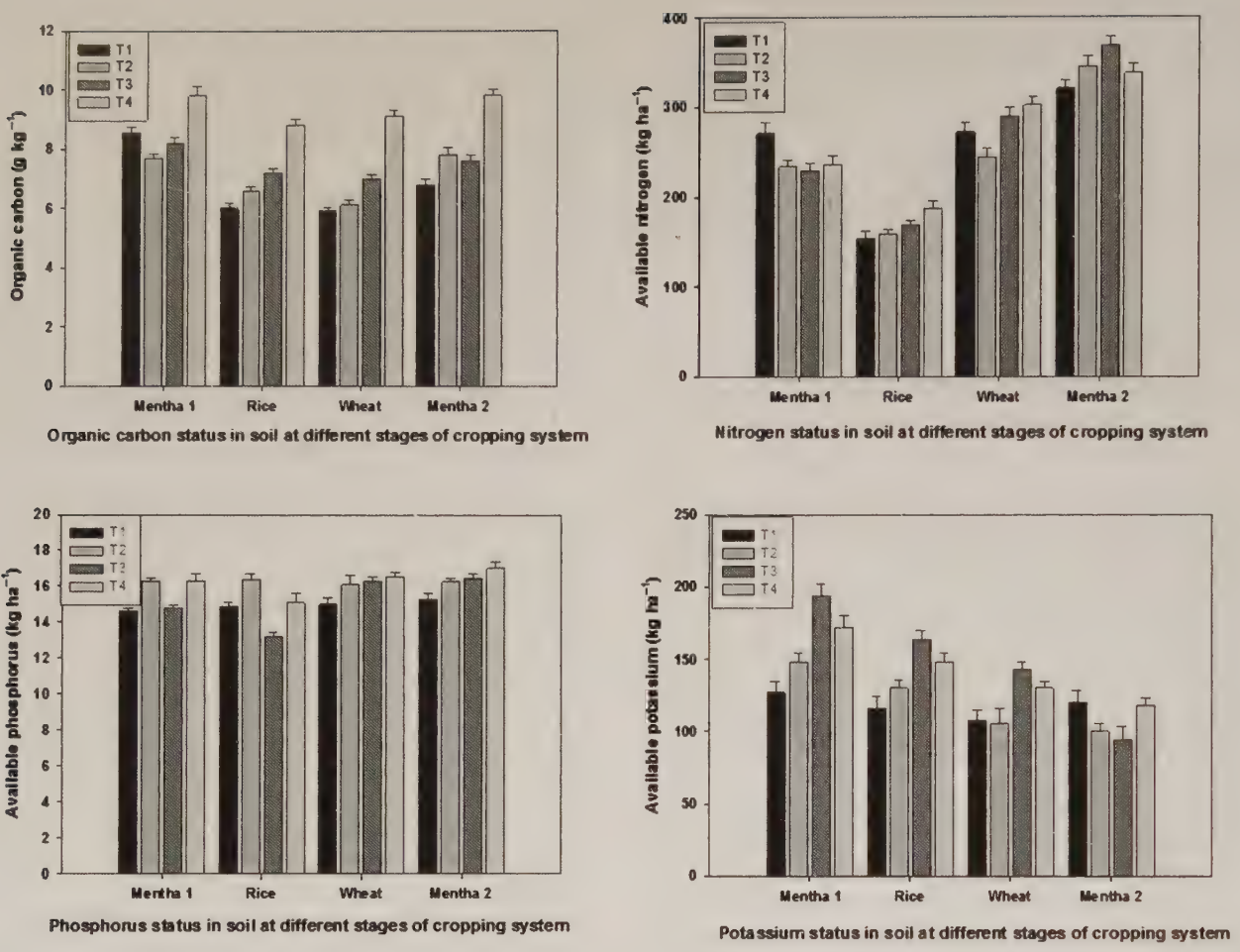
Organic carbon (g kg⁻¹)
T1
T2
T3
T4
Mentha 1
Rice
Wheat
Mentha 2
Organic carbon status in soil at different stages of cropping system
Available nitrogen (kg ha⁻¹)
Nitrogen status in soil at different stages of cropping system
Available phosphorus (kg ha⁻¹)
Phosphorus status in soil at different stages of cropping system
Available potassium (kg ha⁻¹)
Potassium status in soil at different stages of cropping system

Figure 2. Data on nutrient status of soil after harvest of each crop (Experiment 2); vertical error bars indicate the standard error (SE); initial organic carbon = 8.7 g kg^{-1}, initial available nitrogen = 216 kg ha^{-1}, initial available phosphorus = 13.6 kg ha^{-1}, initial available potassium = 148 kg ha^{-1}, T1 = 100% NPK, T2 = 2.5 t ha^{-1} VC + 50% NPK, T3 = 5.0 t ha^{-1} VC + 25% NPK; T4 = 7.5 t ha^{-1} VC; 100% NPK = 75:60:60 kg ha^{-1}; VC = vermicompost.

manure for supplementing the nutritional requirement of the crop(s) in mint–wheat and mint–mustard cropping sequences[1]. VC-based integrated nutrient management has been observed to improve the physical, chemical and biological properties of the soil under *Mentha piperata* and basil (*Ocimum basilicum*)[1,5].

Economic analysis of the production of essential oil as influenced by various treatments revealed that the application of VC along with inorganic fertilizers (T3) increased the total income but failed to improve NI as compared to 100% inorganic fertilizers (T1). Higher cost of fertilizer inputs in T3 probably could not benefit in terms of higher NIs (Fig. 1), but would definitely enhance the overall benefits by improving soil health (Table 3).

A comparison of the data on initial soil chemical properties with those after harvest indicated that soil OC, available N, P_2O_5 and K_2O did show increases in the post-harvest soil. The OC in the soil after the crop harvest increased by 8.0, 19.5, 33.3 and 34.5% over that present before the crop under T1, T2, T3 and T4, respectively; highest being in plots receiving 7.5 t of VC (T4) (Table 3). Highest available N, on the other hand, was observed with T3 (combination of 5.0 t ha^{-1} VC and 25% of the chemical fertilizers) with an increase of 15.4% over the initial value (Table 3). Available phosphorus in the post-harvest soil, which was significantly higher than the initial status, followed the order T3 > T4 > T2 > T1 (Table 3). The available potassium followed almost the identical trend as that of P and the highest K_2O was observed with T3, which was about 20.6% more than the initial value (Table 3). Organic manure significantly improves cation exchange capacity of the soil to hold cations such as K^+ which might have enhanced K availability[21]. All these indicate that VC, besides enhancing the yield of the crop, had a significant role in maintaining and improving soil fertility. Use of VC as the organic manure has been reported to have positive influence on nutrient build-up[22,23], physical parameters such as bulk density and water-stable aggregates[1], and microbial biomass-mediated nutrient turnover[24,25] and survival of beneficial microbes[7]. In this context, the application of VC at

Table 6. Correlation coefficients between soil parameters and yield of menthol mint (*M. arvensis*), rice (*Oryza sativa*) and wheat (*Triticum aestivum*) crops cultivated in farmers' fields (Experiment 2).

Soil parameters	After mint harvest			After rice harvest				After wheat harvest				After mint harvest			
	AN	AP	AK	OC	AN	AP	AK	OC	AN	AP	AK	OC	AN	AP	AK
OC	0.78**	0.37	0.13	0.80**	0.82**	0.09	0.08	0.84**	0.74**	0.66**	0.25	0.81**	−0.64**	0.82**	0.70**
AN		0.40	−0.34	0.45*	0.41	0.53*	−0.33	0.56**	0.26	0.38	−0.28	0.56**	−0.79**	0.60**	0.79**
AP			0.34	0.61**	0.46*	0.45*	0.42	0.56**	0.15	0.75**	0.05	0.76**	0.08	0.18	−0.04
AK				0.59**	0.64**	−0.64**	0.98**	0.51*	0.61**	0.63**	0.90**	0.45*	0.60**	0.22	−0.51*
OC					0.95**	−0.08	0.60**	0.91**	0.79**	0.94**	0.57**	0.92**	−0.15	0.67**	0.25
AN						−0.27	0.60**	0.90**	0.91**	0.85**	0.69**	0.85**	−0.18	0.76**	0.26
AP							−0.51*	−0.11	−0.50**	0.03	−0.82**	0.18	−0.36	−0.13	0.34
AK								0.47*	0.53*	0.66**	0.83**	0.47*	0.65**	0.15	−0.57**
OC									0.80**	0.86**	0.53*	0.86**	−0.26	0.70**	0.34
AN										0.64**	0.77**	0.64**	−0.20	0.83**	0.28
AP											0.50	0.94**	0.01	0.50*	0.10
AK												0.35	0.36	0.41	−0.28
OC													−0.19	0.59**	0.30
AN														−0.54*	−0.98*
AP															0.58*

OC, percent organic carbon; AN, available N; AP, available P; AK, available K.
*, **, Significant at 5 and 1%, respectively.

5 t ha^{-1} with 25% of the recommended dose of NPK had an edge over rest of the treatment combinations.

The results of correlation analysis between soil and mint yield parameters are given in Table 4. Correlation coefficient showed a positive relationship between herb and oil yield and oil content (%) and oil yield. The relationships between soil OC and available N, soil OC and available P and soil OC and available K, soil OC and herb yield, soil OC and oil% and soil OC and oil yield were positive. Also, available N had positive correlation with yield and soil characteristics. The presence of sufficient OC, available P and K probably would have contributed to higher herb and oil yield (Table 4).

Experiment 2

In the second experiment involving similar treatments in mint–rice–wheat–mint-based system, it was also observed that the highest oil yield of mint and grain yield in wheat was recorded in treatment T3; the extent of increase in mint oil yield being 5.6–7.2% and in wheat being 6.6% over the plots receiving the full dose of chemical fertilizers (T1) (100% NPK) (Table 5), whereas there was no significant difference observed in menthol mint oil quality. VC integration with chemical fertilizers may influence above-ground ecosystems by contributing to the plant nutrition, plant health, soil structure and soil fertility in soil[26]. The trend in yield enhancement was different in the case of rice, where the highest yield (3.90 t ha^{-1}) was recorded in T1. Rice is a nutrient-exhaustive crop and this might be attributed to a higher nutrient acquisition in terms of N, P and K[27] as compared to mint. The higher availability of nutrients to the rice plant in plots treated with chemical fertilizers (T1=100% NPK) compared to the other treatments (T4, T3 and T2) might be responsible for higher rice grain yield. This is evident from low OC, N, P and K in post rice harvest soil (Fig. 2). Higher N losses, probably because of leaching in rice fields, coupled with high anaerobic decomposition leading to emission of methane would have contributed to the low OC levels in soil after the harvest of rice. The order of yield in rice was T1 >T4>T3>T2. Wheat yield, however, followed the same trend as that of mint and the highest yield was achieved with T3 (3.73 t ha^{-1}) as compared to the rest of the treatments; the extent of increase was 4, 13 and 6% with T1, T2 and T4, respectively. Likewise, the highest mint oil yield was recorded with T3 and was of the order of T3>T2>T1>T4. The crop sequence mint–rice–wheat again followed by mint in the rotation recorded maximum yield with T3 except in rice. This can be presumed to be due to soil fertility build-up under those treatments. Similar observations have been observed in mint and basil, respectively[1,5], while working on recycling of distillation waste of aromatic herbs.

Data on different soil properties after harvest of each crop (Fig. 2) indicated that soil after harvest of mint (first crop) had a higher N, P, K and OC. On the other hand,

these levels significantly declined after the harvest of rice which might be attributed to a higher nutritional requirement of rice and a greater loss of nutrients, mainly N and K. Nevertheless, all the parameters increased in the subsequent period of the cropping sequence. At all the stages of sampling, the soil receiving VC, in general, had an improved soil fertility status.

The relationship of soil fertility parameters such as soil OC, available N, available P and available K with harvest of each crop was investigated using correlation coefficients (r value) (Table 6). This reveals that soil OC was positively correlated with soil fertility parameters at all harvests except after mint, where available N content in soil showed a negative correlation with soil OC. Significant positive relationships were also recorded with available P at all harvests (Table 6).

Conclusion

The results clearly show that 75% of the inorganic NPK requirement could be reduced by supplementing with the application of VC ($5\,t\,ha^{-1}$) produced from distillation waste of menthol mint, improving the productivity in menthol mint and mint–rice–wheat rotation and fertility of the soil. Use of VC ($7.5\,t\,ha^{-1}$) without chemical fertilizers significantly improved the health of soil but yield benefits could be maximized by integrating the use of VC ($5\,t\,ha^{-1}$) with chemical fertilizers. The present study has demonstrated the potential benefit of recycling of menthol mint de-oiled herb via vermicomposting for increased productivity and better soil health.

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Comparison of crop management strategies involving crop genotype and weed management practices in conventional and more diverse cropping systems

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Abstract

Cropping systems that include forage legumes and small grains in addition to corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] can achieve similar or higher crop productivity and economic return than simpler corn–soybean rotations. We hypothesized that this rotation effect occurs regardless of the crop genotype planted and the herbicide and cultivation regime selected for weed management. To test this hypothesis, we conducted a 3-year experiment that compared three cropping systems: a conventional 2-year corn–soybean rotation, a 3-year corn–soybean–oat (*Avena sativa* L.)/red clover (*Trifolium pretense* L.) rotation, and a 4-year corn–soybean–oat/alfalfa–alfalfa (*Medicago sativa* L.) rotation. Within each cropping system, two contrasting sets of management strategies were used: (i) genetically engineered corn with resistance to insect pests (*Ostrinia nubilalis* Hübner and *Diabrotica* spp.) plus the broadcast application of pre-emergence herbicides, followed in the rotation by a genetically engineered soybean variety with resistance to the herbicide glyphosate plus the post-emergence broadcast application of glyphosate; and (ii) non-genetically engineered corn plus the banded application of post-emergence herbicides, followed in the rotation by a non-genetically engineered soybean and banded application of several post-emergence herbicides. The two management strategies were identified as 'GE' and 'non-GE.' Corn yield was higher in the 3-year (12.51 Mg ha^{-1}) and 4-year (12.79 Mg ha^{-1}) rotations than in the conventional 2-year (12.16 Mg ha^{-1}) rotation, and was also 2% higher with the GE strategy than with the non-GE strategy. Soybean yield was similar among rotation systems in 2008, but higher in the 3- and 4-year systems than the 2-year rotation in 2009 and 2010. Soybean yield was similar between management strategies in 2008, but higher in the GE strategy in 2009, and similar between strategies in the 3- and 4-year rotations in 2010. Increases in rotation length were accompanied by 88–91% reductions in synthetic N fertilizer application, and the use of the non-GE rather than the GE strategy was accompanied by a 93% reduction in herbicide active ingredients applied. Averaged over the period of 2008–2010, net returns to land and labor were highest for the 3-year rotation managed with either the GE ($928 ha^{-1} yr^{-1}) or non-GE ($936 ha^{-1} yr^{-1}) strategies, least in the 2-year rotation managed with the non-GE strategy ($738 ha^{-1} yr^{-1}), and intermediate in the other rotation × management combinations. Our results indicate that more diverse crop rotation systems can be as profitable as conventional corn–soybean systems and can provide farmers with greater flexibility in crop management options.

Key words: diversified cropping systems, forage legumes, crop rotation, weed management, economic return

Introduction

Crop diversity at farm and regional levels in the USA has diminished markedly during the past 50 years[1,2], and monocultures and short rotation sequences are the prevalent cropping systems there and in many other developed countries[3,4]. Simplification of cropping systems has been accompanied by greater reliance on synthetic

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pesticides and fertilizers, while conservation practices have sometimes been abandoned to increase production[5]. Contamination of underground and surface water by nitrogen, herbicides and soil sediment is an on-going concern for agriculturalists[6,7].

One of the major changes in US agriculture over the past two decades has been the wide-scale adoption of genetically engineered crops and associated management practices, creating 'technology packages'. In 2011, 94% of US soybeans were genetically engineered for herbicide tolerance, principally glyphosate tolerance[8]. Similarly, in 2011, 72% of the US corn crop was genetically engineered with traits for herbicide tolerance, insect resistance, or both[8]. Concomitant with the introduction of traits for glyphosate tolerance has been a large increase in the use of glyphosate, making it the most heavily used agricultural pesticide in the USA[9].

The rapid increase in the use of transgenic crops has taken place at the same time as there has been an effort among researchers and policy-makers to raise awareness of the environmental, social and economic consequences of intensive agriculture[10,11]. This effort has led to attempts to improve agricultural sustainability through the design and management of agro-ecosystems that exploit ecological processes to maintain soil productivity, improve crop yield, and manage pest and weed populations[12–15]. Some analysts of genetic engineering for crop production and protection have argued that it can improve agricultural sustainability and should be considered for use with other practices that are common to organic and low-external input (LEI) production systems[16,17]. Other analysts have raised concerns over the durability of genetic engineering approaches, noting the increasing prevalence of weed and insect pest resistance to genetically engineered corn and soybean genotypes[18,19].

LEI cropping systems are intended to reduce environmental, economical and social problems related to intensive pesticides and fertilizer applications[20,21]. LEI cropping systems rely on manipulations of ecological processes, and the agricultural practices performed in these more diverse systems can lead to improvement in soil structure[22], reduction in carbon and nitrogen losses[23,24], added organic matter[25], fixation of atmospheric nitrogen by legumes[26], reduction in the incidence and severity of crop diseases[27,28], reduction in weed density[29,30], increase in soil microbial biomass[31,32], and higher fossil-energy efficiency[33]. LEI systems use green and animal manures and other organic matter amendments as principal nutrient sources for crops, and to improve soil structure. Weed management, an important concern in LEI and organic systems, can be addressed through the application of small quantities of herbicides, cultivation, and other cropping practices, which expose weeds to multiple stress and mortality factors[12].

Various studies have reported higher crop productivity and economic return in more diverse crop rotations than in simpler conventional systems[34,35], while other experiments indicated the contrary[36]. Previously, we reported the results of a multiyear cropping systems experiment established in Iowa to test the hypothesis that yield, weed suppression and profit characteristics of diversified cropping systems can match or exceed those of conventional systems[37]. The experiment included a conventional 2-year corn–soybean rotation, and two more diverse rotations managed with low external inputs: a 3-year corn–soybean–small grain/red clover system, and a 4-year corn–soybean–small grain/alfalfa–alfalfa system. Over a 4-year period (2003–2006), net returns were highest for the 4-year rotation, lowest for the 3-year rotation, and intermediate for the 2-year system, with lower use of synthetic N fertilizer and herbicide in the more diverse rotations[37]. Within that study, however, corn and soybean genotypes were not necessarily the same in the different rotation systems, i.e., rotation systems and management practices were confounded with crop genetic identity.

To address this issue, an experiment was initiated to determine whether effects of cropping system diversity on crop productivity were similar for management strategies that differ in the genotypes planted and the weed management programs implemented. We hypothesized that: (i) more diverse crop rotations can achieve similar or higher corn and soybean yields than a conventional, simpler rotation, regardless of the genotype planted and the herbicide and cultivation regime selected for weed management; and (ii) the total economic return of the more diverse rotations is similar or higher than the conventional, simpler rotation. There are several implications of having a similar increase in productivity though longer rotations, regardless of the genotype sown and weed management strategy implemented. First, it would enhance the flexibility of choosing the crop genotype to be planted according to the needs of each production unit, either for resistance to insects, diseases, or tolerance to certain herbicides. Second, it would reduce the inherent risk of depending on fixed external outputs and consequent price fluctuations. Third, the risk of developing herbicide resistance in weeds might be minimized by allowing the use of small quantities of herbicides with different active ingredients over time. And fourth, by favoring a more resilient agroecosystem, it might be possible to reduce the potential negative impacts of environmental and biotic factors on crop yield.

Materials and Methods

Experimental site

The experiment was conducted at Iowa State University's (ISU's) Marsden Farm, located in Boone County, Iowa. The site characteristics, management history, and agronomic performance of the crops from 2003 to 2008 are reported by Liebman et al.[37] and Cruse et al.[33]. Weather data were collected 1 km from the study site.

In 2008–2010, the experiment was arranged as a split-plot design. Main plot size was 18 m by 85 m. Each crop within each rotation sequence was grown each year, constituting nine main plots in each of the four replicate blocks. The main plots corresponding to corn and soybean were split in halves and one of two sets of management strategies ('GE' or 'non-GE') was assigned to each subplot. For corn, the GE management strategy consisted of a genetically engineered hybrid plus the broadcast application of pre-emergence herbicides; the non-GE strategy consisted of a non-genetically engineered hybrid plus the application of post-emergence herbicides in a 38-cm band over the crop row. The GE corn was a stacked hybrid with genes to control both European corn borer, *Ostrinia nubilalis* Hübner, and corn rootworms, *Diabrotica* spp. For soybean, the GE strategy used a genetically engineered variety with resistance to the herbicide glyphosate plus the post-emergence broadcast application of that herbicide; the non-GE strategy consisted of a non-genetically engineered variety and the application of a mixture of post-emergence herbicides in a 38-cm-band over the crop row. The details of the corn hybrids and soybean varieties planted, and the pre- and post-emergence herbicides applied are provided in Tables 1 and 2.

Crop management

Tillage operations varied among rotation systems. Fall chisel plowing occurred in all the rotations after corn harvest, to partially incorporate corn residue, and a shallow fall disking was performed after soybean harvest in the 3- and 4-year rotations to level the plots. Fall moldboard plowing was carried out in the 3-year rotation to incorporate the red clover and in the 4-year rotation to incorporate the second-year alfalfa. Spring cultivation was performed in all corn plots before planting in 2008–2010, and in soybean plots in 2009 and 2010.

Oat was planted with red clover in the 3-year rotation or with alfalfa in the 4-year rotation in the spring of each year. Oat straw was baled and removed after grain harvest, and red clover was used as a green manure. First-year alfalfa was harvested once in each seeding year and second-year alfalfa was harvested three times in 2008 and four times in 2009 and 2010. Crop hybrid or cultivar, planting and harvest dates, seed density, and row spacing are provided in Table 1.

Soil fertility management differed among rotations: we applied synthetic fertilizers in the 2-year rotation, whereas we used composted cattle manure and reduced rates of synthetic fertilizers in the 3- and 4-year rotations. Fertilizer rates were based on soil tests from each rotation. Soil samples (0–20 cm depth) were collected each fall and submitted to the ISU Soil and Plant Analysis Laboratory to determine P and K requirements. Synthetic nitrogen was applied as urea to corn plots in the 2-year rotation before planting, and the late spring nitrate test was used to determine rates for post-emergence side-dress N applications in all corn plots[38]. In 2009 and 2010, no synthetic nitrogen was applied to corn plots in the 3- and 4-year rotations due to the presence of adequate amounts of nitrate in the soil, according to fertilizer recommendations for Iowa[39]. Composted cattle manure was applied to plots of red clover and alfalfa preceding corn in the 3- and 4-year rotations at a rate of 16.2 Mg ha^{-1} (fresh weight basis). Synthetic fertilizer rates and total calculated N, P, and K applied with the composted manure, following analyses conducted by the ISU Soil and Plant Analysis Laboratory, are shown in Table 3.

As noted previously, weed management differed among rotations and management strategies in corn and soybean plots (Table 2). Banded herbicides were supplemented with inter-row cultivation for weed control in the non-GE corn and soybean subplots. This cultivation occurred once in corn and twice in soybean in 2008, and two times in corn and soybean in 2009 and 2010. Oat stubble in the 3- and 4-year rotations was mowed 28–35 days after grain harvest to control weeds (Table 2). No explicit weed control was performed in established alfalfa plots.

To control soybean aphid (*Aphis glycines* Matsumura), we applied the insecticides lambda-cyhalothrin (0.027 kg a.i. ha^{-1}) on August 13, 2008 and chlorpyrifos (0.531 kg a.i. ha^{-1}) on August 14, 2009 to all soybean plots; no insecticide was applied in 2010.

Yield determination and data analysis

Six rows (382 m^2) of each corn and soybean subplot were harvested using a combine and grain yield was measured in a weigh wagon. Corn weight was adjusted to reflect a moisture concentration of 155 g kg^{-1}, whereas soybean weight was adjusted to a moisture concentration of 130 g kg^{-1}. Oat grain was harvested from entire plots (1530 m^2) using a combine, and the weight was adjusted to a moisture concentration of 140 g kg^{-1}. Alfalfa and oat straw were clipped and baled from entire plots, and the weight of the bales was determined and adjusted to a moisture concentration of 150 g kg^{-1} and 100 g kg^{-1}, respectively.

Yield of each crop was analyzed separately. Analyses of variance (ANOVAs) of corn and soybean yields were performed using the MIXED procedure of SAS, specified for analysis of a split-plot experiment repeated over 3 years[40]. Rotation and management strategy were considered fixed factors, and replication and year as random factors. Orthogonal contrasts were used to analyze corn and soybean yield of: (i) the 2-year rotation versus the average of the 3- and 4-year rotations (simple versus more diverse systems); and (ii) the 3-year rotation versus the 4-year rotation (comparison between diverse rotations). Oat yield was analyzed using the GLM procedure of SAS, with rotation as a fixed factor and replication and year as random factors. Alfalfa yield over the 3 years was analyzed using the GLM procedure.

Table 1. Hybrid or cultivar grown, planting and harvest date, seed density, seed mass and inter-row spacing used in contrasting crop rotations.

Crop[1]	Year	Management strategy	Hybrid or cultivar	Planting date	Harvest date	Seed density (seeds ha^{-1})	Seed mass (kg ha^{-1})	Inter-row spacing (cm)
Corn	2008	Post/non-GE	Agrigold 6395	May 19	November 3	79,530	–	76
Corn	2009	Post/non-GE	Agrigold 6395	April 23	October 21	79,530	–	76
Corn	2010	Post/non-GE	Agrigold 6395	April 20	October 8	79,530	–	76
Corn	2008	Pre/GE	Agrigold 6395BtRW	May 19	November 3	79,530	–	76
Corn	2009	Pre/GE	Agrigold 6395BtRw	April 23	October 21	79,530	–	76
Corn	2010	Pre/GE	Agrigold 6395BtRW	April 20	October 9	79,530	–	76
Soybean	2008	GLY/GE	Kruger 287RR	May 21	October 6	382,850	–	76
Soybean	2009	GLY/GE	Kruger 287RR	May 12	October 27	395,200	–	76
Soybean	2010	GLY/GE	Kruger 287RR	May 19[2]	October 5	395,940	–	76
Soybean	2008	MIX/non-GE	Kruger 2918	May 21	October 6	382,850	–	76
Soybean	2009	MIX/non-GE	Kruger 2918	May 12	October 27	395,200	–	76
Soybean	2010	MIX/non-GE	Kruger 2918	May 19[2]	October 5	395,940	–	76
Oat	2008	–	IN09201	April 16	August 4	–	83	20
Oat	2009	–	IN09201	April 1	July 20	–	78	20
Oat	2010	–	IN09201	April 1	July 16	–	81	20
Red clover	2008	–	Cherokee	April 16	–	–	13	20
Red clover	2009	–	Duration	April 1	–	–	13	20
Red clover	2010	–	Medium	April 1	–	–	13	20
Alfalfa	2008	–	FSG 400LH	April 16	June 20, August 1, September 17	–	17	20
Alfalfa	2009	–	Freedom LH	April 1	June 3, July 6, August 17, September 15	–	17	20
Alfalfa	2010	–	Freedom LH	April 1	May 28, July 12, August 20, November 30	–	17	20

[1] Corn and soybean were planted in all the rotation systems, oat was planted with either red clover in the 3-year rotation or with alfalfa in the 4-year rotation.
[2] In 2010, soybean was planted on May 19 in blocks 1–3 and on May 25 in block 4.

Weed biomass sampling and data analysis.

In corn plots, above-ground weed biomass in eight 3.05 × 0.76 m areas per sub-plot was clipped on September 30, 2008, September 23, 2009 and September 14, 2010, and then dried and weighed. The same methodology was used to determine weed biomass in soybean sub-plots on October 2, 2008, September 24, 2009 and September 30, 2010. In oat stubble with red clover, oat stubble with alfalfa, and second year alfalfa plots, weed biomass was collected, and then dried and weighed, from eight 0.25 m^2 randomly placed quadrats per plot on October 10, 2008, October 6, 2009 and October 15, 2010. Weed biomass values were transformed ($\ln [x+1]$) to meet the ANOVA requirement for normal distribution. The same ANOVA and orthogonal contrasts performed in the crop yield analyses were used to test for differences in weed biomass, within the same crop, among years, rotations and management strategies.

Economic analysis

Labor requirements, costs and returns for the different rotation system and management strategy combinations were assessed using data from various sources. Labor times for machinery operations were based on values presented by Hanna[41] and costs for labor and machinery wear and maintenance were assigned based on reports by Duffy[42–44]. Costs for fertilizer, seed, pesticides, interest on loans, crop insurance and miscellaneous items were estimated using data from Duffy[42–44] and local agricultural dealers. We considered an integrated low-external-cropping system representative of the region, where the crops are fed to livestock and cattle manure

Table 2. Weed management practices for each crop rotation from 2008 to 2010. Rate (kg ha^{-1}) of herbicide active ingredients shown in parentheses.

Crop	Management strategy	2008	2009	2010
		2-year rotation		
Corn	Pre/GE	PRE, broadcast: S-metolachlor (1.981), isoxaflutole (0.088)	PRE, broadcast: S-metolachlor (1.820), isoxaflutole (0.070)	PRE, broadcast: S-metolachlor (1.820), isoxaflutole (0.070)
Corn	Post/non-GE	POST, banded: nicosulfuron (0.013), rimsulfuron (0.007), mesotrione (0.053); inter-row cultivation (1)	POST, banded: nicosulfuron (0.013), rimsulfuron (0.007), mesotrione (0.053); inter-row cultivation (2)	POST, banded: nicosulfuron (0.013), rimsulfuron (0.007), mesotrione (0.053); inter-row cultivation (1)
Soybean	GLY/GE	POST, broadcast: glyphosate (1.121)	POST, broadcast: glyphosate (1.121)	POST, broadcast: glyphosate (1.401)
Soybean	MIX/non-GE	POST, banded: clethodim (0.051), lactofen (0.053), flumiclorac pentyl ester (0.015); inter-row cultivation (2)	POST, banded: clethodim (0.051), lactofen (0.070), flumiclorac pentyl ester (0.015); inter-row cultivation (2)	POST, banded: clethodim (0.051), lactofen (0.088), flumiclorac pentyl ester (0.023); inter-row cultivation (2)
		3-year rotation		
Corn	Pre/GE	PRE, broadcast: S-metolachlor (1.981), isoxaflutole (0.088)	PRE, broadcast: S-metolachlor (1.820), isoxaflutole (0.070)	PRE, broadcast: S-metolachlor (1.820), isoxaflutole (0.070)
Corn	Post/non-GE	POST, banded: nicosulfuron (0.013), rimsulfuron (0.007), mesotrione (0.053); inter-row cultivation (1)	POST, banded: nicosulfuron (0.013), rimsulfuron (0.007), mesotrione (0.053); inter-row cultivation (2)	POST, banded: nicosulfuron (0.013), rimsulfuron (0.007), mesotrione (0.053); inter-row cultivation (1)
Soybean	GLY/GE	POST, broadcast: glyphosate (0.121)	POST, broadcast: glyphosate (1.121)	POST, broadcast: glyphosate (1.401)
Soybean	MIX/non-GE	POST, banded: clethodim (0.051), lactofen (0.053), flumiclorac pentyl ester (0.015); inter-row cultivation (2)	POST, banded: clethodim (0.051), lactofen (0.070), flumiclorac pentyl ester (0.015); inter-row cultivation (2)	POST, banded: clethodim (0.051), lactofen (0.088), flumiclorac pentyl ester (0.023); inter-row cultivation (2)
Oat + red clover	–	Stubble mowing (1)	Stubble mowing (1)	Stubble mowing (1)
		4-year rotation		
Corn	Pre/GE	PRE, broadcast: S-metolachlor (1.981), isoxaflutole (0.088)	PRE, broadcast: S-metolachlor (1.820), isoxaflutole (0.070)	PRE, broadcast: S-metolachlor (1.820), isoxaflutole (0.070)
Corn	Post/non-GE	POST, banded: nicosulfuron (0.013), rimsulfuron (0.007), mesotrione (0.053); inter-row cultivation (1)	POST, banded: nicosulfuron (0.013), rimsulfuron (0.007), mesotrione (0.053); inter-row cultivation (2)	POST, banded: nicosulfuron (0.013), rimsulfuron (0.007), mesotrione (0.053); inter-row cultivation (1)
Soybean	GLY/GE	POST, broadcast: glyphosate (0.121)	POST, broadcast: glyphosate (1.121)	POST, broadcast: glyphosate (1.401)
Soybean	MIX/non-GE	POST, banded: clethodim (0.051), lactofen (0.053), flumiclorac pentyl ester (0.015); inter-row cultivation (2)	POST, banded: clethodim (0.051), lactofen (0.070), flumiclorac pentyl ester (0.015); inter-row cultivation (2)	POST, banded: clethodim (0.051), lactofen (0.088), flumiclorac pentyl ester (0.023); inter-row cultivation (2)
Oat + alfalfa	–	Stubble mowing; hay removal (1)	Stubble mowing; hay removal (1)	Stubble mowing; hay removal (1)
Alfalfa		Hay removal (3)	Hay removal (4)	Hay removal (4)

is applied to the crop fields. Manure was assumed to be generated by on-farm livestock and therefore free, but the costs of spreading it, i.e., labor and machinery, were calculated using data from Hanna[41] and Duffy[42–44]. Iowa market year crop prices were obtained from the USDA National Agricultural Statistics Service [45].

We placed primary emphasis on determining the economic performance characteristics of the whole rotation systems under contrasting management strategies, rather than the economic performance of individual crop phases within the different rotations. Consequently, we evaluated gross revenue and net returns to land and

Table 3. Fertilization regimes for crops grown in contrasting crop rotations from 2008 to 2010.

Crop	2008	2009	2010
	2-year rotation		
Corn	20 kg P + 49 kg K ha^{-1} as TSP[1] and KCl before planting; 114 kg N ha^{-1} as urea at planting; 102 kg N ha^{-1} after planting as UAN[2]	112 kg N ha^{-1} as urea at planting; 56 kg N ha^{-1} after planting as UAN	178 kg K ha^{-1} before planting as KCl; 59 kg P ha^{-1} before planting as TSP; 112 kg N ha^{-1} as urea at planting; 63 kg N ha^{-1} after planting as UAN
Soybean	20 kg P + 49 kg K ha^{-1} as TSP and KCl before planting	None	178 kg K ha^{-1} before planting as KCl; 59 kg P ha^{-1} before planting as TSP
	3-year rotation		
Corn	119 kg N + 69 kg P + 92 kg K ha^{-1} as composted manure before planting; 102 kg N ha^{-1} after planting as UAN	122 kg N + 52 kg P + 113 kg K ha^{-1} as composted manure before planting	83 kg N + 43 kg P + 73 kg K ha^{-1} as composted manure before planting; 90 kg K ha^{-1} before planting as KCl
Soybean	None	None	90 kg K ha^{-1} before planting as KCl
Oat + red clover	None	None	90 kg K ha^{-1} before planting as KCl
	4-year rotation		
Corn	20 kg P + 49 kg K ha^{-1} as TSP and KCl before planting; 119 kg N + 69 P + 92 kg K ha^{-1} as composted manure before planting; 102 kg N ha^{-1} after planting as UAN	122 kg N + 52 kg P + 113 kg K ha^{-1} as composted manure before planting	83 kg N + 43 kg P + 73 kg K ha^{-1} as composted manure before planting; 178 kg K ha^{-1} before planting as KCl
Soybean	20 kg P + 49 kg K ha^{-1} as TSP and KCl before planting	None	178 kg K ha^{-1} before planting as KCl
Oat + alfalfa	20 kg P + 49 kg K ha^{-1} as TSP and KCl before planting	None	178 kg K ha^{-1} before planting as KCl
Alfalfa	20 kg P + 49 kg K ha^{-1} as TSP and KCl before planting	none	178 kg K ha^{-1} before planting as KCl

[1] TSP: triple super phosphate.
[2] UAN: urea ammonium nitrate.

Table 4. Mean monthly air temperature and precipitation determined 1 km from the study site in Boone, IA.

	Mean monthly air temperature (°C)				Total monthly precipitation (mm)			
Month	**2008**	**2009**	**2010**	**Long-term mean[1]**	**2008**	**2009**	**2010**	**Long-term mean[1]**
April	8.4	8.9	13.0	9.8	133	116	93	90
May	15.2	15.7	16.1	16.1	216	96	92	115
June	21.3	21.1	21.7	21.2	271	104	284	124
July	23.3	20.4	23.7	23.2	236	70	171	103
August	21.6	20.2	24.0	21.9	53	123	285	106
September	17.9	18.1	17.7	17.6	78	24	167	80
October	11.6	7.3	12.6	11.2	92	186	14	63
November	2.4	6.5	3.4	2.8	66	35	59	42

[1] Long-term mean for 1951–2010.

management on a unit land area basis, with land units divided into two equal portions for corn and soybean in the 2-year rotation; three equal portions for corn, soybean, and oat with red clover in the 3-year rotation; and four equal portions for corn, soybean, oat with alfalfa, and alfalfa in the 4-year rotation. Net returns to land and management represented returns to a farm operation calculated without accounting for costs of land (e.g., rent or mortgage payments) or management time (e.g., marketing). Split-plot ANOVAs were conducted to examine variation in gross revenue and net returns, using year and block as random factors and rotation system (main plot) and management strategy (sub-plot) as fixed factors. Orthogonal contrasts were conducted to examine rotation effects, as described above for corn and soybean yield analyses. Treatment interactions with year were significant for both gross revenue and net returns, causing us to analyze results separately by year. However, we also evaluated these response variables averaged over the period of 2008–2010, as a means of examining economic performance over a longer time frame. For simplicity in presentation, we evaluated mean costs for each rotation system and management strategy combination by category averaged over the period of 2008–2010.

Results

Weather conditions

Air temperature did not differ from the long-term mean in any of the 3 years (Table 4). Precipitation fluctuation in 2008 and 2010 was significant. May, June and July 2008 were very wet months (Table 4), some plots were occasionally flooded for 2–3 days during those months. Very wet conditions also occurred in June and August of 2010 (Table 4).

Nitrogen fertilizer and herbicide use

The quantity of synthetic nitrogen applied in the corn phase of the 3- and 4-year rotations was five times lower than in the corn phase of the conventional 2-year rotation (Table 5). Likewise, the overall synthetic nitrogen used in the 3- and 4-year rotations was 88 and 91% lower than in the 2-year rotation, respectively (Table 5). There were no differences in nitrogen use among management strategies.

Table 5. Mean herbicide and synthetic nitrogen fertilizer use over 2008–2010 in the three crop rotations.

Rotation	Herbicides (kg a.i. $ha^{-1} yr^{-1}$)	N fertilizer (kg N $ha^{-1} yr^{-1}$)
2-year		
Corn pre/GE	1.950	186.3
Corn post/non-GE	0.073	186.3
Soybean GE	1.214	0.0
Soybean non-GE	0.139	0.0
Rotation average GE strategy	1.582	93.2
Rotation average non-GE strategy	0.106	93.2
3-year		
Corn pre/GE	1.950	34.0
Corn post/non-GE	0.073	34.0
Soybean GE	1.214	0.0
Soybean non-GE	0.139	0.0
Oat/red clover	0.000	0.0
Rotation average GE strategy	1.055	11.3
Rotation average non-GE strategy	0.071	11.3
4-year		
Corn pre/GE	1.950	34.0
Corn post/non-GE	0.073	34.0
Soybean GE	1.214	0.0
Soybean non-GE	0.139	0.0
Oat/alfalfa	0.000	0.0
Alfalfa	0.000	0.0
Rotation average GE strategy	0.791	8.5
Rotation average non-GE strategy	0.053	8.5

Table 6. Mean corn yield over the years 2008–2010.

	Management strategy	
	GE	**Non-GE**
	----------Mg ha^{-1}----------	
Rotation system		
2-year	12.49	11.82
3-year	12.59	12.43
4-year	12.82	12.75
SE	0.24	0.24
	----------*P*----------	
Effects		
Rotation	0.08	
Management	0.03	
Rotation*Management	0.29	
Contrasts		
2-year versus (3-year + 4-year)/2	0.04	
3-year versus 4-year	0.4	

Table 7. Soybean yield from 2008 to 2010 involving three rotations and two management strategies.

	2008		**2009**		**2010**	
	GE	**Non-GE**	**GE**	**Non-GE**	**GE**	**Non-GE**
	----------Mg ha^{-1}----------					
Rotation system						
2-year	3.61	3.32	3.56	3.24	2.83	1.45
3-year	3.73	3.58	4.18	3.43	3.64	3.73
4-year	3.94	3.99	4.05	3.85	3.69	3.59
SE	0.18		0.26		0.44	
	----------*P*----------					
Effects						
Rotation	0.0968		0.1046		0.0003	
Management	0.0580		0.0307		0.0034	
Rotation*Management	0.1308		0.3941		0.0012	
Contrasts						
2-year versus (3-year + 4-year)/2	0.0819		0.0460		<0.0001	
3-year versus 4-year	0.1508		0.5315		0.82	

Herbicide use was lower in the non-GE strategy than in the GE strategy in all the rotations due to banded applications (Table 5). Similarly, less herbicide was applied in the longest, most diverse rotation (Table 5) because weed control was done mechanically in the oat + alfalfa and alfalfa phases.

Crop yields

Corn. The main effect of year was not significant ($P = 0.2743$), and no interactions were detected among years, rotations or management strategies. In 2008, standing water in one plot corresponding to the 3-year rotation with the GE management strategy caused a reduction in plant density and therefore a reduction in corn yield. This particular value was considered an outlier in the dataset after testing the normality of the distribution. We then performed an ANOVA and orthogonal contrasts with and without the outlying observation, and with the data transformed ($\log_e x$) and untransformed. The outlier made the rotation main effect in the ANOVA not significant, whether or not the data were transformed. However, this value was not removed from the dataset because the significant rotation main effect remained evident through orthogonal contrasts (Table 6).

Corn yield was highest in the 4-year rotation (mean = 12.79 Mg ha^{-1}), lowest in the 2-year rotation (mean = 12.16 Mg ha^{-1}) and intermediate in the 3-year rotation (mean = 12.51 Mg ha^{-1}) (Table 6). There were significant differences in corn yield between the conventional 2-year rotation and the more diverse 3- and

Table 8. Oat grain and alfalfa hay yield from 2008 to 2010.

Crop	Year	Rotation system			SE
		2-year	3-year	4-year	
		---------- $Mg\,ha^{-1}$ ----------			
Oat[1]	2008	–	3.17	3.30	0.15
Oat[1]	2009	–	3.56	3.69	0.10
Oat[1]	2010	–	3.23	3.50	0.13
Alfalfa[2]	2008	–	–	9.96	0.35
Alfalfa[2]	2009	–	–	5.48	0.17
Alfalfa[2]	2010	–	–	12.12	0.35

[1] Mean yield of harvested oat straw in the 3-year rotation was 2.82, 2.81 and 1.86 $Mg\,ha^{-1}$ in 2008, 2009 and 2010, respectively, and 2.59, 2.67 and 1.74 $Mg\,ha^{-1}$ in the 4-year rotation.
[2] Alfalfa hay yield for second-year stands. Mean first-year alfalfa hay yield was 1.03, 1.21 and 1.13 $Mg\,ha^{-1}$ in 2008, 2009 and 2010, respectively.

4-year rotations, but no differences were detected between the 3- and 4-year systems (Table 6). We also detected higher corn yield in the GE management strategy (mean = 12.63 $Mg\,ha^{-1}$) compared with the non-GE management strategy (mean = 12.33 $Mg\,ha^{-1}$), in all the rotations (Table 6), although this difference was small.

Soybean. Soybean yield was affected by a significant three-way interaction among year, rotation and management strategy ($P = 0.0022$), therefore, soybean yield was analyzed separately by year. Orthogonal contrasts highlighted the higher soybean yield in the longer rotations versus the conventional corn–soybean rotation in 2009 and 2010 (Table 7).

The ANOVA for each year detected significant differences in soybean yield between management strategies in 2009 and 2010 (Table 7). These differences could be the result of abiotic and biotic factors affecting the soybean plants in those years. In 2009, we observed severe temporary defoliation in the non-GE subplots sprayed with lactofen, but no precise quantification was made on each plot. In 2010, low soil temperatures at planting and high soil moisture during the summer favored the attack of the soil-borne pathogen *Fusarium virguliforme* Aoki & T. Aoki, which caused the disease known as sudden death syndrome (SDS). In the 2-year rotation, this attack affected 96% of the soybean plants in the non-GE management strategy and 27% of the soybean plants in the GE strategy[46]. In contrast, in the 3- and 4-year rotations, fewer than 9% of the soybean plants of either management strategy were affected by SDS[46].

Oat and alfalfa. Oat grain yield was similar between rotations ($P = 0.1018$) and between years 2008 and 2010, but higher in 2009 ($P = 0.0250$) (Table 8). Alfalfa hay yield differed among years ($P < 0.0001$): it was highest in 2010 (12.12 $Mg\,ha^{-1}$), lowest in 2009 (5.48 $Mg\,ha^{-1}$), and intermediate in 2008 (9.96 $Mg\,ha^{-1}$) (Table 8). The differences in alfalfa yield among years could be attributed to extreme environmental conditions, such as flooding in spring of 2008 and summer of 2009.

Weed biomass. Overall, weed biomass in all the corn and soybean plots was very low (Table 9). Because of the few weeds present and their patchy distribution, the data were not normally distributed and the variability was high. This situation is common in agricultural fields with low weed density[47]. The dominant weeds were *Taraxacum officinale* F.H. Wigg. aggr., *Setaria faberi* R.A.W. Herrm., *Amaranthus rudis* J.D. Sauer, *Abutilon theophrasti* Medik. and *Chenopodium album* L. The triple interaction of year, rotation and management strategy was significant for weed biomass in corn plots ($P = 0.0079$), therefore weed biomass was analyzed by year. Weed biomass in corn was greater in the 4-year rotation with the non-GE management strategy in 2008, and in the 2-year rotation with the GE strategy in 2010. Higher weed biomass was detected in the non-GE than GE corn subplots in 2009 (Table 9). In soybean plots, no differences in weed biomass were evident among rotations or between management strategies (Table 9). Weed biomass in oat intercropped with a legume was affected by the interaction between year and rotation ($P = 0.0289$). Weed biomass in oat did not differ between rotations in 2008 and 2010, but was lower in the 3-year rotation in 2009 (Table 9).

Economic analysis. In 2008, gross revenue was higher in the 2-year rotation ($1623 $ha^{-1}\,yr^{-1}$) than in the 3-year ($1472 $ha^{-1}\,yr^{-1}$) and 4-year ($1526 $ha^{-1}\,yr^{-1}$) rotations, but was unaffected by management strategy (Fig. 1A; Table 10). Similarly, in 2009, gross revenue was higher in the 2-year rotation ($1474 $ha^{-1}\,yr^{-1}$) than in the 3-year ($1284 $ha^{-1}\,yr^{-1}$) and 4-year ($1210 $ha^{-1}\,yr^{-1}$) rotations, but it was also greater with the GE ($1353 $ha^{-1}\,yr^{-1}$) than the non-GE ($1292 $ha^{-1}\,yr^{-1}$) management strategy (Fig. 1B; Table 10). In 2010, gross revenue was affected by an interaction between rotation system and management strategy such that gross revenue was greatest in the 2-year rotation managed with the GE strategy ($1806 $ha^{-1}\,yr^{-1}$), least in the 2-year rotation managed with the non-GE strategy ($1466 $ha^{-1}\,yr^{-1}$) and intermediate in the other rotation and management combinations (Fig. 1C; Table 10). Average gross revenue for the period of 2008–2010 was greatest for the 2-year rotation managed with the GE strategy ($1662 $ha^{-1}\,yr^{-1}$), least for the 3-year rotation managed with the non-GE strategy ($1422 $ha^{-1}\,yr^{-1}$), and intermediate for the other rotation and management combinations (Fig. 1D; Table 10).

Two general patterns were evident for total production costs (Fig. 2). First, total production costs were highest for the 2-year rotation (mean = $780 $ha^{-1}\,yr^{-1}$), least for the 3-year rotation (mean = $511 $ha^{-1}\,yr^{-1}$) and intermediate for the 4-year rotation (mean = $620 $ha^{-1}\,yr^{-1}$). Second, the GE management strategy was slightly more costly

Table 9. Weed biomass in crop rotations involving two management strategies from 2008–2010. Transformed (ln [x+1]) means are in parentheses.

Crop	Rotation system	Management strategy	Year					
			2008		2009		2010	
			$g\,m^{-2}$					
Corn	2-year	GE	0.26	(0.22)	0.23	(0.20)	1.18	(0.71)
Corn	2-year	Non-GE	0.11	(0.10)	0.65	(0.44)	0.18	(0.15)
Corn	3-year	GE	6.18	(0.96)	0.28	(0.24)	0.17	(0.15)
Corn	3-year	Non-GE	2.81	(0.78)	1.15	(0.73)	0.70	(0.44)
Corn	4-year	GE	0.16	(0.15)	0.40	(0.32)	0.17	(0.15)
Corn	4-year	Non-GE	2.24	(1.09)	1.44	(0.85)	0.25	(0.22)
	SE[1]			(0.39)		(0.13)		(0.15)
Soybean	2-year	GE	0.06	(0.06)	0.25	(0.22)	0.17	(0.16)
Soybean	2-year	Non-GE	0.50	(0.40)	0.26	(0.22)	0.40	(0.32)
Soybean	3-year	GE	0.37	(0.28)	0.22	(0.19)	0.05	(0.05)
Soybean	3-year	Non-GE	0.26	(0.21)	4.48	(0.85)	0.25	(0.21)
Soybean	4-year	GE	0.07	(0.07)	0.06	(0.06)	0.02	(0.02)
Soybean	4-year	Non-GE	0.24	(0.17)	0.07	(0.06)	0.24	(0.20)
	SE			(0.09)		(0.28)		(0.07)
Oat	3-year	–	10.09	(2.17)	0.31	(0.26)	9.12	(1.77)
Oat	4-year	–	7.04	(1.82)	6.88	(2.04)	10.14	(2.38)
	SE			(0.40)		(0.11)		(0.51)
Alfalfa	4-year	–	1.27	(0.76)	51.50	(3.93)	7.93	(2.18)
	SE			(3.81)		(3.81)		(3.81)

[1] Transformed (ln[x+1]) standard error of the mean.

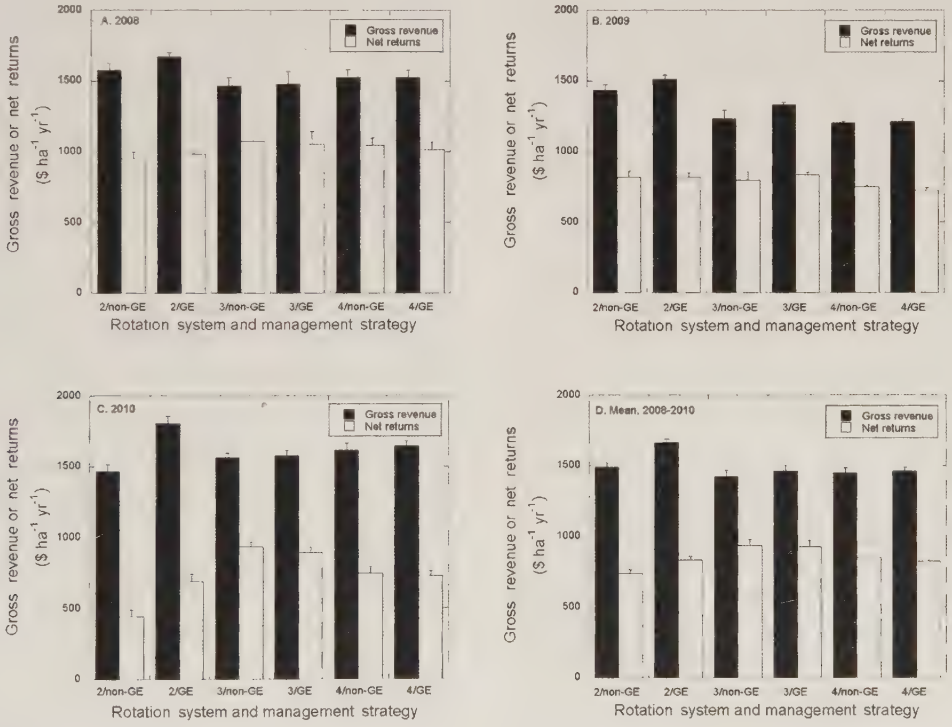

Figure 1. Annual and mean gross revenue and net returns of crop management strategies in each rotation system.

than the non-GE strategy in each rotation (mean difference = $\$44\,ha^{-1}\,yr^{-1}$). With regard to cost categories, higher synthetic fertilizer costs were incurred by the 2-year rotation ($\$278\,ha^{-1}\,yr^{-1}$) than in the 3-year ($\$57\,ha^{-1}\,yr^{-1}$) and 4-year ($\$142\,ha^{-1}\,yr^{-1}$) rotations. Higher quantities of synthetic nitrogen in the 2-year

Table 10. ANOVA of economic returns.

ANOVA	2008		2009		2010		Mean, 2008–2010	
	Gross revenue	Net returns	Gross revenue	Net returns	Gross revenue	Net returns	Gross revenue	Net returns
Effects				*P*				
Rotation	0.0360	0.1644	0.0005	0.0761	0.4451	0.0018	0.0063	0.0062
Management	0.0668	0.7632	0.0186	0.8707	<0.0001	0.0013	<0.0001	0.0069
Rotation*Management	0.1064	0.3221	0.2770	0.4696	<0.0001	<0.0001	<0.0001	<0.0001
Contrasts								
2-year versus (3-year + 4-year)/2	0.0171	0.0825	0.0002	0.1978	0.4668	0.0013	0.0022	0.0077
3-year versus 4-year	0.2700	0.4615	0.0620	0.0490	0.3055	0.0153	0.6707	0.0155

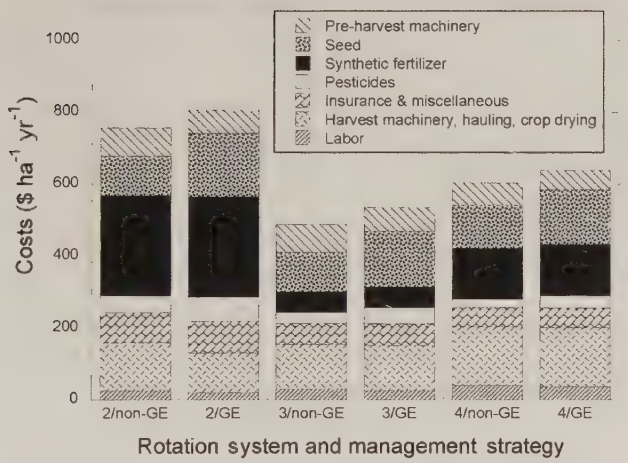

Figure 2. Production costs of crop management strategies in each rotation system.

rotation, and lower quantities of P and K applied in the 3-year rotation explain these differences (Table 3). Seed costs were higher with the GE (mean = \$162 $ha^{-1} yr^{-1}$) than the non-GE (mean = \$114 $ha^{-1} yr^{-1}$) strategies. Pre-harvest machinery and operations costs differed little among rotations, but greater harvest expenses were incurred in the 4-year rotation (mean = \$164 $ha^{-1} yr^{-1}$) than the 3-year (mean = \$125 $ha^{-1} yr^{-1}$) and 2-year (mean = \$122 $ha^{-1} yr^{-1}$) systems due to harvest of alfalfa. Expenses for pesticides decreased with rotation length and increased with the use of the GE management strategy. Conversely, labor costs increased with rotation length, reflecting added work in plowing legume sod and spreading manure before planting corn, but decreased with the use of the GE management strategy, reflecting the absence of inter-row cultivation in corn and soybean with the GE strategy. Labor costs were, however, relatively small (<6.5%) in all rotation × management combinations. Insurance and miscellaneous expenses were lower in the more diverse rotation systems than in the conventional 2-year system.

Despite differences among rotation systems and management strategies in gross returns and production costs, net returns to land and management were unaffected by rotation and management in 2008 (Fig. 1A; Table 10). However, in 2009, net returns were higher in the 2-year (mean = \$819 $ha^{-1} yr^{-1}$) and 3-year (mean = \$818 $ha^{-1} yr^{-1}$) rotations than in the 4-year (mean = \$739 $ha^{-1} yr^{-1}$) rotation, though they remained unaffected by management strategy (Fig. 1B; Table 10). In 2010, net returns were affected by a strong interaction between rotation system and management strategy (Fig. 1C; Table 10). Net returns in 2010 were greatest in the 3-year rotation and did not differ within that system between non-GE (\$937 $ha^{-1} yr^{-1}$) and GE strategies (\$891 $ha^{-1} yr^{-1}$). The 4-year rotation provided lower net returns than did the 3-year rotation in 2010 and there was no difference between the non-GE (\$743 $ha^{-1} yr^{-1}$) and GE (\$728 $ha^{-1} yr^{-1}$) management strategies. A significant difference was detected in 2010 between management strategies for the 2-year rotation, with lower net returns generated by the non-GE system (\$442 $ha^{-1} yr^{-1}$) than the GE strategy (\$692 $ha^{-1} yr^{-1}$). Average net returns for the period of 2008–2010 were greatest in the 3-year rotation regardless of whether it was managed with the non-GE (\$937 $ha^{-1} yr^{-1}$) or GE strategy (\$928 $ha^{-1} yr^{-1}$) (Fig. 1D; Table 10). The other rotation systems produced significantly lower net returns with significant differences between management strategies evident in both the 4-year rotation (non-GE: \$847 $ha^{-1} yr^{-1}$; GE: \$823 $ha^{-1} yr^{-1}$) and the 2-year rotation (non-GE: \$738 $ha^{-1} yr^{-1}$; GE: \$831 $ha^{-1} yr^{-1}$) (Fig. 1D: Table 10).

Discussion

This study and previous publications[33,37] have been consistent in showing higher productivity of corn and soybean in rotations that are more diverse than the conventional corn–soybean system that is prevalent in the US Midwest, despite the lower use of synthetic fertilizer and herbicides. In the present study, composted manure

and legume residues provided sufficient quantities of nitrogen so that no synthetic fertilizer was applied to the 3- and 4-year rotations in 2009 and 2010. The N made available from legume residues and composted manure in more diverse rotations is likely to be released more slowly than N provided by commercial fertilizers and may therefore be less susceptible to leaching into subsurface drainage lines that discharge into streams and lakes[24]. This represents an important potential advantage at a time when reducing water contamination by nitrate comprises an important goal for the design of sustainable agricultural systems[10]. In the present study, the net economic returns from the more diverse rotation systems were high or higher than the conventional 2-year rotation, even when the labor requirement was higher in the more diverse systems. Higher economic return in the 3-year rotation than the 4-year rotation was due to the application of lower quantities of P and K in the 3-year rotation. The alfalfa hay harvested from plots of the 4-year rotation removed P and K that was not offset sufficiently by manure application, while the red clover was not removed but incorporated into the soil in the 3-year rotation.

We also found that in the more diversified 3- and 4-year rotation systems it was possible to implement management strategies that differ in crop genotypes and weed management activities, including the herbicides applied, without altering substantially the net economic returns of the cropping system. In the conventional 2-year rotation system, in contrast, choice of management strategy strongly affected net returns. It is important to note that these two management strategies do not constitute an extensive comparison between genetically engineered and conventional crop performance, but rather an evaluation of two specific sets of management tactics in which particular genotypes were coupled with chemical and/or physical weed control practices.

More diverse cropping systems that include crops with different botanical characteristics and the addition of organic matter increase microbial biomass and enhance the functional diversity of microbial communities that affect multiple processes within the soil, limiting the impact of some crop pathogens[28,48] and potentially making the system more resilient. As an example, in the present work, we observed in 2010 a severe outbreak of SDS of soybean, in the 2-year rotation. The appearance of this disease was widespread in soybean fields in Iowa in 2010 and favored by certain weather and soil conditions[46]. In the soybean plants of the 3- and 4-year rotations, however, SDS incidence was much lower and similar between management strategies, suggesting a rotation effect that operates similarly regardless of the crop genotype planted[46]. In a similar cropping systems experiment, Porter et al.[1] suggested an association between higher disease incidence observed in a 2-year corn–soybean rotation with lower soybean yield, compared to a 4-year corn–soybean–oat/alfalfa–alfalfa rotation, although they did not identify the diseases affecting soybean plants or quantify disease incidence or severity.

Having similar economic return regardless of the management strategy implemented gives the farmer higher flexibility when choosing the corn and soybean genotype to be planted and the herbicides to be applied, and decreases the risk associated with depending on a specific management strategy over time. Similarly, the N supplied by composted manure and legumes made the more diverse rotation systems less reliant on synthetic N, and therefore less affected by the variability in fertilizer prices.

Oat productivity in the 3- and 4-year rotations and alfalfa productivity in the 4-year rotation had important impacts on the rotation total economic return. Oat grain and alfalfa hay yields varied significantly among years, and both were less profitable than corn or soybean (data not shown). In order to maintain high rotation economic return, it is important to maximize the productivity of oat and alfalfa. Although weed biomass was low in both crops, when cold weather conditions reduced the alfalfa stand in 2009, weed seedlings emerged and colonized empty spaces, affecting crop growth. Weed biomass was significantly higher in 2009 because of the successful colonization of *T. officinale* in certain areas of the plots where the alfalfa plants were damaged. Nonetheless, weed management was generally successful in both conventional and more diverse systems, and in both management strategies. The implications of these results are that farmers who plant non-genetically engineered genotypes in more diverse cropping systems may achieve the same weed control as with genetically engineered crops, and would be less likely to depend on a single herbicide as the control method, thereby reducing the risk of selection for herbicide resistant weeds.

We conclude that diversified cropping systems can be as profitable as simpler, conventional systems, require less synthetic nitrogen and herbicide use, give greater crop management flexibility to farmers, and can be more resilient to biotic factors that affect crop performance. We acknowledge, however, that broad-scale shifts to diversified systems from the conventional corn–soybean system will favor changes in crop prices, due to changes in supply, which may create economic forces that countervail diversification. Policy and economic incentives that encourage cropping system diversification as a means of reducing agrichemical use, retarding the evolution of herbicide resistance in weeds, and improving environmental quality will likely be required to promote substantial change on a landscape level.

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Opportunities and constraints to legume diversification for sustainable maize production on smallholder farms in Malawi

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Abstract

Sustainable intensification of smallholder farms in Africa is highly dependent on enhancing biological nitrogen fixation (BNF). Legume diversification of maize-based systems is a core example of sustainable intensification, with the food security of millions of farm families at stake. This study highlights the constraints and opportunities associated with the adoption of legumes by smallholder farmers in southern Africa. A two-part survey of households and farm fields ($n = 88$) was conducted in the Ekwendeni watershed of northern Malawi. Participatory research and education activities have been underway for over a decade in this region, resulting in expanded uptake of a range of legume species as intercrops and in rotation with the staple maize crop. Farmer adoption has occurred to a varying extent for soybean (*Glycine max*), pigeon pea (*Cajanus cajan*), velvet bean (*Mucuna pruriens*) and fish bean (*Tephrosia vogelii*). Farmers, working with the project valued pigeon pea and other legumes for soil fertility purposes to a greater extent than farmers not working with the project. Legumes were valued for a wide range of purposes beyond soil cover and fertility enhancement, notably for infant nutrition (at least for soybean), insect control, and vegetable and grain production for both market and home consumption. Literature values for BNF in tropical legumes range up to 170 kg N ha^{-1} for grain and 300 kg N ha^{-1} for green manure species; however, our field interviews illustrated the extent of constraints imposed by soil properties on smallholder fields in Malawi. The key edaphic constraints observed were very deficient to moderate phosphorus levels (range 4–142, average 33 mg kg^{-1}), and moderately acid soils (range pH 5.1–7.9, average 6.2). The per farm hectarage devoted to legume production relative to maize production was also low (0.15 versus 0.35 ha), a surprising find in an area with demonstrated interest in novel legume species. Further, farmers showed a strong preference for legumes that produced edible grain, regardless of the associated nutrient removal in the harvested grain, and did not sow large areas to legume crops. These farm-level decisions act as constraints to BNF inputs in maize-based smallholder cropping systems. Overall, we found that legume productivity could be enhanced. We documented the value of policies and educational efforts that support farmers gaining access to high-quality seeds, amendments for phosphorus-deficient soils, and promotion of multipurpose legumes that build soils through leafy residues and roots, as well as providing grain for food security and sales.

Key words: integrated soil fertility management, smallholder farmer, sustainable intensification

Introduction

Nutrient deficiencies are a major factor limiting productivity on smallholder farms in sub-Saharan Africa (SSA), as soils are widely infertile and farmers have limited access to amendments such as inorganic fertilizers and manure[1]. Legume diversification in rain-fed cereal production has been shown to have positive effects on soil organic matter (OM) and nitrogen through crop residue incorporation and biological nitrogen fixation (BNF), moisture conservation and soil microbial activities[2–4]. However, legume production is often limited in scope[5], constraining contributions to agricultural nutrient cycling and sustainability[6,7].

The potential benefits—and challenges—associated with integrating more legumes into maize-based cropping systems are complex[8]. The benefits of legumes on soil OM pools, soil fertility and cropping system production will

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vary based on edaphic factors, genetics and management practices[9]. A case study in northern Malawi is evaluated here. A small, landlocked country in southern Africa, Malawi is highly representative of rain-fed, smallholder maize production across the continent. The majority of farmers in Malawi have an average land holding size of <1 ha. The staple food crop is maize (*Zea mays* L.), which is cultivated on >70% of arable land[10]; secondary crops include tobacco (*Nicotiana tabacum*), cotton (*Gossypium hirsutum*), cassava (*Manihot esculenta*) and groundnut (*Arachis hypogaea*).

Constraints and opportunities related to legume crop production have been studied in some detail in northern Malawi[11]. A unique opportunity is presented by the slow but steady rate of expansion in legume cultivation that has been underway over the past decade (Fig. 1). In Malawi, the most common legumes grown include bean (*Phaseolus vulgaris*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*) and pigeon pea (*Cajanus cajan*), frequently grown as intercrops in southern Malawi, whereas sole stands of groundnut and bambara groundnut (*Vigna subterranea*) are typical of northern Malawi[11]. Maize and legume crop area and yield data show increased production of maize[12], groundnut and pigeon pea from 1998 to 2009, while area planted to soybean has fluctuated (Fig. 1).

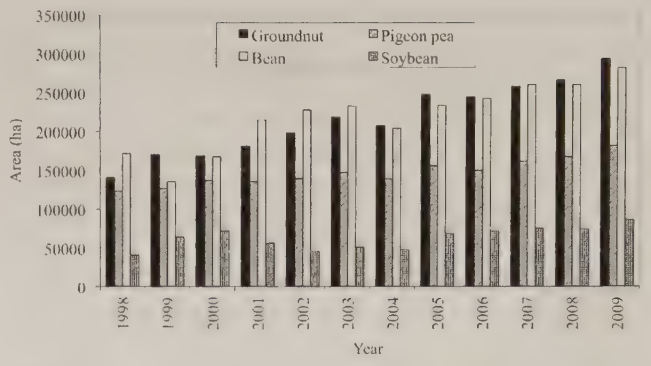

Figure 1. Total area of groundnut, pigeonpea, common bean and soybean production in Malawi, 1998–2009. Source: FAO, FAOSTAT (http://faostat.fao.org).

Legume performance

Legume growth and rhizobial nodulation are highly dependent on adequate moisture and aeration. Temperature gradients can also influence legume production, but across tropical Africa the climate is generally sufficiently warm for most legume species and moisture is the more widespread constraint. Rainfall is a particularly important factor in annual legume biomass production and N inputs. In one study, biomass production in cowpea (*V. unguiculata*) was found to be 34% higher in high rainfall areas (900 mm annual precipitation) than in low rainfall sites (450 mm annual precipitation)[13]. In a study in Kenya, low rainfall was associated with lower yields of intercropped grain legumes and maize[4]. Generally, insufficient rainfall limits legume growth; however, excess moisture and extreme rainfall events are becoming major problems for African crop production. This was highlighted in a recent decadal analysis of three long-term experiments located in Nigeria, Zambia and Malawi. Grain yield loss was more often associated with excess rainfall than insufficient rainfall[14]. Many leguminous crops require well aerated soils and have almost no tolerance of flooded conditions, as might be expected given the high energy demands associated with microbial symbionts and N fixation.

Soil factors, including both biological and geochemical properties, exert a major influence on legume performance[15]. Deficiencies of soil N and inorganic P are some of the most widespread constraints to legume development and yield potential, and nowhere is this more evident than in Africa. Phosphorus affects root growth and development, nodulation and the N fixation process[3,16]. This is not surprising, given the energetic demands of the BNF process and high requirements for ATP synthesis. To enhance BNF on smallholder farms, one of the most effective management practices is to amend legume fields with a phosphorus source, such as manure or inorganic fertilizer[17,18].

Different growth habits and management practices are associated with legumes grown for soil fertility properties. These include viny plants, shrubs and trees grown as part of green manure and agroforestry systems. Sequential or relay intercrops are frequently used for these types of dedicated soil improvement systems. Agroforestry, or the integration of woody species with herbaceous plants such as food crops, green manures and pastures, can provide a variety of goods and services, including food, fodder, soil fertility improvement, soil erosion control and biopesticides[19–21]. Examples of leguminous woody species include fish bean (*Tephrosia volgelii*), gliricidia (*Gliricidia sepium*), winterthorn (*Faidherbia albida*), sesbania (*Sesbania sesban*) and leuceana (*Leuceana leucocephala*). However, barriers to adoption of green manure and agroforestry systems include seed availability, pests in some tree species and unpredictable rainfall patterns, as well as concern for lack of sufficient short-term benefits, and the opportunity cost of allocating arable land to trees as opposed to food crops, and labor inputs.

Legume growth characteristics

The growth habits and other characteristics of legumes vary by species and variety (Table 1). Some of the characteristics can be complementary, depending on the species and management practices; for example, differences in growth habits allow intercropping of maize with pigeon pea, fish bean or climbing bean. Similarly, upright groundnut varieties or soybean can be intercropped with pigeon pea. Intercropping, if carefully designed and managed, can help to increase resource-use efficiency[22]. However, reported constraints to adoption include limited

Table 1. Characteristics of selected legumes that can influence smallholder farmer preferences (sources: information on legume characteristics and use from Malawi Government, MOAIFS[24]; legume traits adapted from Snapp and Silim[25]).

	Name of legume					
Trait	**Pigeon pea**	**Groundnut**	**Soybean**	**Cowpea**	**Velvet bean**	**Fish bean**
Tolerance to low soil fertility	High	Med	Med-high	High	High	High
Tolerance to drought	High	Low	Low	High	Med-high	High
Improve soil fertility	High	Med	Med	Med	High	High
Market potential	Med	High	High	High	None or yes[1]	None
Food value	Yes	Yes	Yes	Yes	None or yes[1]	None[2]
Grain yield	Low	Med-High	Med-High	Low	High	None
Suitability for green manure	Low	None	None	None	High	High
Maturity period	Med-long	Short-med	Short	Short-med	Short-med	Long
Growth habit	Determinate/ indeterminate	Determinate	Determinate/ indeterminate	Determinate/ indeterminate	Indeterminate	Determinate
Labor demand	Med	High	High	Low	Low	Med
Intercropping potential	Very good[3]	Fair[4]	Fair[4]	Good[5]	None	Good[5]
Other secondary benefits	Yes (fuel wood)	None	None	None	Yes (weed control)	Yes (insecticide, fish bait, firewood)

Note: med = medium.
[1] Velvet bean is usually grown as a green manure. However, people in the southern region of Malawi prepare delicious snacks from velvet beans and eat or sell them. Recipes are not well known in the central and northern regions, and if not well cooked and processed, velvet beans can be poisonous.
[2] Not suitable for human consumption.
[3] Intercropped with maize or groundnut or soybean.
[4] Groundnut or soybean are usually grown in pure stands. However, either of the two legumes can be intercropped with pigeon pea.
[5] Intercropped with maize.

markets for grain and access to seeds as well as increased labor requirements[23]. Total N fixed over time varies widely depending on legume species and variety, site, weather, soil and crop management practices, and cropping system. The net N and soil fertility benefits from legumes are influenced by residue N inputs and nitrogen harvest index (NHI). The net N benefit is minimal or nil from high grain harvest crops such as soybean where often over half of the aboveground N is removed in the grain[26]. Conversely, species with a lower NHI that are grown primarily for inputs from N-enriched tissues, such as green manures, perennial agroforestry and indeterminate legumes, have been shown to have greater soil fertility benefits than annuals, determinate and grain legumes[7,15]. Grain legumes with low harvest indices grown primarily for vegetative materials, such as long-duration soybean, are best characterized as multipurpose legumes.

On-farm measurements of BNF have been reported for many species. The values range from low in common bean (8–31 kg N ha^{-1})[7] to a wide range for soybean (3–112 kg N ha^{-1})[27,28] and groundnut (22–124 kg N ha^{-1})[29–31]. Higher N fixation values are generally associated with longer lived crops such as pigeon pea (37–164 kg N ha^{-1})[6,32] and leguminous tree species (44–277 kg N ha^{-1})[33–35]. Values in SSA have been reported to be as high as 170 kg N ha^{-1} for grain legumes[28,32] and 300 kg N ha^{-1} for green manures[7]. It is known that on-farm performance of legumes is generally much reduced compared to the potential shown by research studies, but specific edaphic constraints to legume performance have rarely been documented, nor is it known which farmer criteria are key influences on adoption and area sown to legume crop species. The unique focus of our study was to document—at the field and farm family scale—the biophysical and socio-economic factors that influenced expansion of legume adoption and nitrogen fixation in a smallholder environment.

The study objectives were to: (1) determine if farmers who participated with the Soils, Food and Healthy Communities (SFHC) project had greater knowledge of legume crops and grow more of them than the farmers who had not participated; (2) document farmer adoption and criteria for assessment of legume crops; and (3) document soil properties associated with specific fields, management and cropping species history.

Materials and Methods

Case study background

Since 2000, SFHC, a project of the Ekwendeni Mission Hospital, has provided nutritional and agronomic education to promote legume diversification, and supported gains in soil fertility and family nutrition in Ekwendeni, Mzimba district, northern Malawi[11,36]. The hospital, which offers medical services to the entire watershed, established the program to address the poor nutrition among children from surrounding communities, especially those below the age of 5. In an earlier study, low crop yields were among the factors associated with malnutrition[36]. The SFHC project focused initially on promoting legume production and educating farmers on residue management and food preparation. Some of the legumes promoted for integration into traditional maize rotation and intercropping systems included improved varieties of groundnut, soybean, pigeon pea, velvet bean and fish bean. The project farmers received training on the agronomy of legume production, post-harvest utilization of various grains, and residue management with legumes to improve soil fertility and family nutrition[11].

The project farmers are organized into farmer research teams (FRTs) to facilitate farmer experimentation and sharing of experiences on legume technologies (production and utilization)[11]. The FRTs are selected by the villagers and they conduct field demonstrations in their communities. The demonstration plots act as learning centers for a wider community and the technologies are disseminated through field days and nutrition education days.

Study site

Malawi has a semi-arid to sub-humid tropical climate with two main seasons, a wet season (October–March) and a dry season (April–September). Almost all maize is grown without irrigation during the wet season. Most soils on smallholder farms are low in nutrient status and depleted in OM[37]. Soils on smallholder farms include a wide range of textures, but a dominant type is coarse-textured, well-drained Alfisols. The government subsidy programs have partially improved access to fertilizers by subsidizing access among smallholder families to one or two bags of fertilizer[38], but fertilizer use remains low to moderate[5].

The study site is the Ekwendeni watershed, located in northern Malawi. Ekwendeni lies at 11°20′S, 33°53′E, with an elevation of 1200 m and annual rainfall of 800–1200 mm[25] from December to March. Annual precipitation in the Ekwendeni watershed averaged 817 ± 212 mm for the period from 1996 to 2007, a moderately low 10-year average but generally sufficient for maize production if the rain is well distributed over the rainy season. The soils are classified as fine kaolinitic, thermic, typic kandiustalfs with low OM ($< 15\,g\,kg^{-1}$)[39].

Surveys

Household and farm field surveys were conducted in June 2007 using two semi-structured interview instruments, the initial instrument documented farm household socio-economic characteristics, knowledge of and use of legumes, and farmer criteria for evaluating legume crop species. The second instrument was used to elicit management history and crop species associated with two specific fields per farm family, where each field was subsequently soil sampled. Farmers were asked to choose two fields, one that was primarily used for maize production, and the other that had been used for legume production.

The selection of farmers for the interviews was done through a multiple step process, starting with random selection of eight villages from among the 60 villages located within the SFHC project area. Within each village, 5–6 farmers were randomly selected for the interviews. Two-thirds of the survey respondents represented project farmers (actively involved with SFHC) and one-third were control farmers (did not work with SFHC, although all farmers had heard of the project). The surveys were conducted by the first author, who is a native speaker of the local language. Specifically, the data collected through the questionnaires administered to household heads included the farm family members, numbers of adults and children, food security status (self-defined) crops grown generally, how legume crops are utilized, traits associated with preferred legumes and constraints to legume production.

After each household interview was completed, a farm field interview process was conducted. As the basis for this interview—a field-specific questionnaire was administered which documented a 3-year history of crop species grown and management practices—two fields/farm were identified for the interview, in consultation with farmers. This included a predominantly maize field (continuous maize with not more than one other crop rotated or intercropped in the last 4 years) and a legume-diversified field (three or more legume crops grown as sole crops or intercrops with maize over the last 4 years). The objective was to compare soil fertility status on 'maize' and 'legume-diversified' fields, as indicated by biological and chemical properties (soil OM, nitrogen, phosphorus, magnesium, calcium and potassium).

A total of 88 fields were identified, as paired sets of fields from 44 farms. This allowed us to evaluate how soil properties and land use varied, in relation to the field-specific interview. Soil sampling was conducted in the fields, as follows. From each field, composite soil samples (10 random subsamples per field) were collected at 0–15 and 15–30 cm soil depth. The samples were mixed, air-dried, passed through a 2 mm sieve, and stored. A subsample of the soil was dried overnight at 40°C, ground and analyzed for OM, pH, available phosphorus (P), exchangeable potassium (K), magnesium (Mg) and calcium (Ca)[40]. The OM was determined by loss on ignition at

Table 2. Means and standard errors of soil chemical properties and texture of legume and maize diversified fields, 0–15 and 15–30 cm soil depths, $N = 44$.

Variable	Depth (cm)	Legume field	Maize field	SED	Pr > (t)
pH (in H_2O)	0–15	6.2	6.3	0.10	0.749
	15–30	6.1	6.1	0.11	0.849
OM ($g\,kg^{-1}$)	0–15	12	13	0.6	0.137
	15–30	13	13	0.6	0.813
Bray P ($mg\,kg^{-1}$)	0–15	24a	34b	3.5	0.012[1]
	15–30	14	13	2.4	0.381
Ca ($mg\,kg^{-1}$)	0–15	418	494	61	0.220
	15–30	411	434	48	0.638
Mg ($mg\,kg^{-1}$)	0–15	101	126	6	0.855
	15–30	100	121	8	0.503
K ($mg\,kg^{-1}$)	0–15	110	121	9	0.746
	15–30	113	121	10	0.974
CEC ($cmol\,kg^{-1}$)	0–15	4.1	4.4	0.3	0.401
	15–30	4.4	4.4	0.2	0.950
Sand (%)	0–15	86	86	0.7	0.594
	15–30	73	73	1.5	0.919
Clay (%)	0–15	9	9	0.6	0.832
	15–30	21	21	1.3	0.748

Means in a row followed by same letters are not statistically significant at $P < 0.05$; SED = standard error of the difference for the paired fields.
[1] Inorganic P is based on Bray I extract.

360°C and the data correlated with Walkley–Black. Soil pH was determined in a 1:1 soil to water slurry. Available P and exchangeable cations were extracted according to Mehlich III[41], and analyzed by inductively coupled plasma spectrometry. These P data were correlated to and reported as Bray P[42]. The data for exchangeable cations were correlated to and reported as a 1 N ammonium acetate extraction[43]. Particle size distribution and particulate OM were determined using gravimetric sedimentation[44].

Statistical analysis

Frequencies and percentages were computed for categorical variables (marital status, education level and preferred legume characteristics) using SPSS statistical software[45]. A chi-squared analysis of equal proportions was performed to test for association between farmer involvement with SFHC and utilization of legumes or crop residue management, using SAS statistical software[46]. Multiple regressions were performed to evaluate the relationship between OM and soil properties. Normality of residuals was checked using normal probability plots[47]. The presence of outliers was examined using Cook's D values.

Multicollinearity was assessed using a correlation procedure and a variance inflation ratio. The best fitted model was selected based on stepwise regression procedures. Data analysis was conducted using PROC UNIVARIATE and PROC REG of SAS[46]. The effects were declared significant at a 5% level of significance.

Results and Discussion

Biophysical environment

The study site is representative of one of the most common land use systems in the sub-humid tropics, which has been termed the mixed maize farming system. Precipitation is highly variable but averages approximately 1000 mm annually in a unimodal pattern starting sometime around December and lasting for about 4 or 5 months. Unpredictable weather patterns contribute to variable production in the region and are expected to increase in variability in the coming decades with global climate change[48]. Recent studies have highlighted the vulnerability of cereal-based farming in southern Africa[49].

Soil resources are important determinants of the vulnerability and resilience of cropping systems[50]. The soil properties observed in this study were consistent with a well-drained soil of predominantly coarse to medium loam texture with an average sand content ranging from 72 to 86% and clay content from 9 to 22% (Table 2). The soil pH was slightly acidic to neutral, 6.1 ± 0.6 in 15–30 cm to 6.2 ± 0.6 in the 0–15 cm soil layer. Soil OM levels were generally low and varied considerably ($12 \pm 4\,g\,kg^{-1}$). At the 0–15 cm soil depth, cation exchange capacity (CEC) was the only factor positively related to OM variation across fields ($R^2 = 0.316$). A wide range of OM values ($5–20\,g\,kg^{-1}$) has been reported for Malawi smallholder farms from a previous country-wide survey[37], whereas higher values than reported here were observed at a Malawi research station ($25–35\,g\,kg^{-1}$)[51]. Our findings of $13\,g\,kg^{-1}$ average OM at the surface soil depth were

Table 3. Number of farmers growing legume species in 2006/2007 season and proportion indicating that a legume species is new (not grown historically at this site).

Variable	Farmer category	Pigeon pea	Groundnut	Soybean	Common bean	Velvet bean	Fish bean
Legume growers	Project	94[1B]	100	100[B]	71	42	22
	Control	69[A]	100	62[A]	77	39	0
	Mean	82	100	81	73	40	11
	Prob	0.04	NS	0.001	NS	NS	0.09
New legume	Project	97	6	97	0	100	57
	Control	78	15	100	0	80	0[2]
	Mean	92	9	97	0	94	–
	Prob	0.07	NS	NS	NS	0.10	–

[1] Figure reported as percent growers within the farmer category.
[2] None of the control farmers grew fish bean.
NS not significant at $P=0.05$.
Means in a column followed by same letters are not different at $P=0.01$ per category.

similar to an earlier soil survey conducted in northern Malawi which reported 15 g kg^{-1} OM[37].

Nutrient status overall was moderate to deficient, and there were a few detectable differences in soil chemical properties between fields with a different cropping system history (compare maize and legume-diversified fields, Table 2). The exception was inorganic P in the 0–15 cm soil layer, which was 50% higher ($P=0.012$) in maize fields (40 ± 21 mg kg^{-1}) than in legume fields (27 ± 18 mg kg^{-1}). Soil pH was moderately acid (6.2) and phosphorus was on an average 34 mg kg^{-1} for maize fields and 24 mg kg^{-1} for legume fields (Table 2). In Malawi, the critical level of inorganic Bray P for field crops is 20 mg kg^{-1} [39], thus the fields surveyed were generally low to medium in available soil P. All other chemical properties documented in this experiment were within a range favorable for the growth of most tropical crops[52]. Overall, the soil phosphorus data indicates that a beneficial practice at a majority of the field sites would be a modest dose of P fertilizer applied to enhance legume growth.[53,54]

The higher P status that was observed on maize fields relative to legume-diversified fields could be attributed to strategic allocation by farmers, where maize is sown on fertile soils. It might also relate to fertilizer amendments applied preferentially to maize production fields. This is supported by the soil fertility amendments reported, which were generally higher for maize fields than legume-diversified fields. Consistent with our findings, a study in Kenya found that farmers tended to focus soil fertility amendments on maize, which was produced on the highest soil fertility areas of the farm[55].

Household characteristics

The results from the survey show that the average age of the household head was 43 (2.3) and the household size was 5 (0.4); the standard error is presented in parentheses. We were interested in labor availability, and asked about the number of adults (defined here as 13 and older) and children in the household. This information was used to calculate the dependency ratio (number of children per adult household member), which averaged 0.9. Our broad definition of adult included youths of 13 years, and we note that 15 is more generally considered the cut-off age for adult members of a family in the region. An earlier smallholder farm survey carried out in central and southern Malawi found a quite similar household size: however, the dependency ratio was lower than observed here[23]. The percentage of households self-defined as food insecure was 41%, which is consistent with previously reported high levels of malnutrition in the area[11].

Cropping system characteristics

The legumes grown by farmers in this study area were, in order of decreasing frequency, as follows: groundnut, soybean, pigeon pea, common bean, cowpea, velvet bean and fish bean (Table 3). Other legumes were grown on a small scale, notably bambara groundnut and chickpea (*Cicer arietinum* L.). The cropping system arrangements documented included sole crop, intercrop and crop rotation. The intercropped legumes were generally grown in mixtures with maize or in legume–legume mixtures consisting of an SFHC-promoted 'doubled up legume' system of the long-duration, shrubby legume pigeon pea grown with an understorey of a short-duration grain legume, usually soybean or groundnut. In the second season of the legume–legume intercrop, pigeon pea was ratooned (after pods were harvested, the main stem was cut back to about 0.5 m high) and regrown as an intercrop with maize[8].

In some farmers' fields the maize–legume intercropping system prioritized maize production, as shown by the high plant population density of maize, which was maintained at ~36,000 plants per ha, a level recommended for sole stands. An intercropped legume crop such as pigeon pea or soybean was generally grown at a moderate density, following an additive design. In contrast, when groundnut was intercropped with pigeon pea, the density of groundnut was reduced as compared to a groundnut only stand. Interestingly, farmers demonstrated local innovation capacity through experimenting with different density

Table 4. Summary of preferred characteristics associated with grain legumes.

	Preferred traits ranked in order of importance			
Legume	**1**	**2**	**3**	**4**
Groundnut	High yield	Wide adaptation to varied soil types and rainfall distribution	High oil content	Improve soil fertility
Pigeon pea	Improve soil fertility	High yield	Early maturity	Grain taste as relish
Soybean	High nutritional value[1]	High yield	Improve soil fertility	Marketable
Common bean	High yield	Grain taste as relish[2]	Early maturing; resistant to pests and diseases; improve soil fertility[3]	Marketable
Cowpea	High yield	Grain taste as relish	Early maturing; resistant to pests and diseases; marketable[3]	None

[1] Farmers indicated interest in child feeding with this crop, and thus high nutritional value for this purpose.
[2] Relish is the local name used to describe the sauce that accompanies the staple maize dish, a key ingredient for food security.
[3] More than one trait listed, ranked the same by farmers.

patterns beyond the recommended combinations, including intercropping the ratooned pigeon pea with maize in the subsequent season at a range of densities depending on soil type and utilization-based criteria. The cropping system innovations are consistent with an earlier report from this region[11].

Farmer evaluation of legumes

The major species characteristics influencing legume adoption included grain yield, adaptation to different environments, soil fertility benefits, maturity period, grain quality (size, taste), resistance to pests and diseases, and market potential (Table 4). Farmers preferred legumes with multiple desired characteristics. High yield was the number one criterion used by farmers in selecting grain legumes, with the exception of pigeon pea, where soil fertility benefits were frequently top priority. Grain quality ranked second after yield in common bean and cowpea (Table 4). Surprisingly, market potential was only mentioned as the third to fifth desired characteristic for a number of legumes, including cowpea, soybean, pigeon pea and groundnut. However, it was a major use of legumes grown, accounting for 12–31% of end use (Fig. 2). Previous studies reported that yield and grain characteristics (size, color and pod size) were the most important criteria for evaluating cowpea[56] and common bean[57]. Labor costs associated with cowpea management[56] and other plant characteristics (uprightness, height from lowest pods)[57] have also been reported as traits associated with preferred varieties.

Farmers strongly preferred edible grain-producing legumes, such as groundnut and pigeon pea, over green manure legumes, such as velvet bean and fish bean. Novel grain legumes were adopted relatively rapidly, while adoption of green manure crops was slow to nil (Table 3). Survey data indicated that farmers were not generally familiar with soybean, pigeon pea, velvet bean and fish bean before the SFHC project was established,

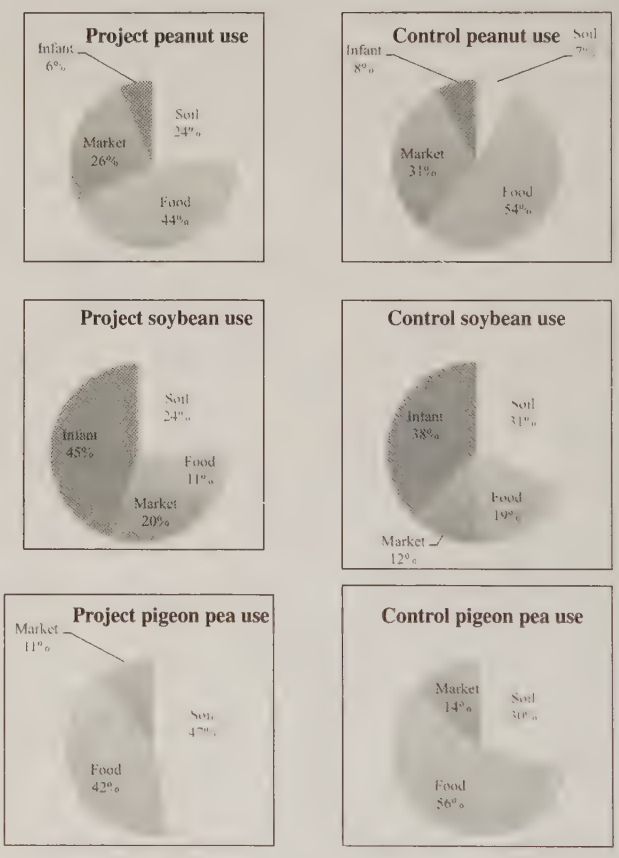

Figure 2. Utilization of grain legume species by SFHC project farmers and control farmers. End use was reported by farmers surveyed, and included market sales, soil fertility improvement (abbreviated 'soil'), food (home consumption) and infant feeding.

whereas now the adoption of soybean and pigeon pea is widespread. The adoption of fish bean and velvet bean was shown to be less common, and only the project farmers had adopted fish bean (Table 3). Overall, as hypothesized, interaction with the SFHC project staff and

Table 5. Major constraints to production of legumes.

Legume	Constraints	Category of constraint
Groundnut	Lack of money to buy seed	Socio-economic household
	Storage of CG7 grain	Agronomy, post-harvest handling
Pigeon pea	Pests in the field and storage	Agronomic
	Late maturity	
	Low yield	
Soybean	Low yield on low fertility soils	Agronomic
Common beans	Lack of money to buy seed	Socio-economic household
	Seed not available	Socio-economic policy
	Low yield; insects pests;	Agronomic
	inadequate or too much rainfall	Natural
Bambara groundnut	Lack of money to buy seed	Socio-economic household
	No markets	Socio-economic policy
	Cultural belief	Socio-cultural
Cowpea	Seed not available	Socio-economic
	Low yield	Agronomic
Velvet bean	Lack of markets; seed not available	Socio-economic policy
Fish bean	Not edible	Socio-economic household

educational programs was associated with increased legume adoption.

Legume utilization

The legumes were primarily used for household consumption, infant nutrition, soil fertility and for sale at market (Fig. 2). Infant nutrition describes the specific role of legumes in enriching weaning food and as a nutritious supplement for the diet of young children. The results were consistent with the adoption of new legume crops based largely on home consumption demand, and to a moderate extent, market demand (Table 4). Farmers who interacted with the SFHC were more likely to appreciate the benefits of legumes for the dual purposes of soil fertility and food security. Project farmers were twice as likely to grow groundnut for soil fertility as farmers who were not involved with the SFHC (Fig. 2).

Our interviews documented that more than 60% of the households grow soybean grain (*G. max*), as a source of oil, protein and vitamins[58], to prepare food for children. Soybean has been promoted heavily by the SFHC project through education on the nutritional value and methods for preparation of soybean porridge, extraction of soybean milk, and use of soybean flour to enrich the staple food (maize porridge) and vegetables[11]. Project farmers were more likely to grow soybean than control farmers ($P = < 0.001$) (Table 3). Pigeon pea was grown for both soil fertility benefits and food, as well as occasionally for market (Fig. 2). Additional uses of pigeon pea were mentioned by some farmers, such as stems for firewood and traditional medicine (Table 4). Firewood from pigeon pea can be a significant contribution to rural communities where high population and deforestation has led to clearing of natural forests[23].

Velvet bean and fish bean were grown primarily for soil fertility, whereas about 20% of the project farmers grew velvet bean for sale. Velvet bean can be eaten if extensively processed, and the grain is a traditional crop in some districts of southern Malawi; however, it can take up to 8 h of cooking to remove the L-DOPA (3,4-dihydroxyphenylalanine), a toxic substance found in the grain that can be fatal if not well processed[59,60]. Velvet bean can help control weeds through allelopathy[23,59] and hence can be used in integrated weed management. In addition to modest adoption of fish bean for soil fertility, many farmers were interested in the plant for its toxic leaves, which can be crushed to produce a bio-pesticide used to control weevils and grain borers during grain storage[61].

Legume production challenges

Farmer-identified constraints to legume production are shown in Table 5. Seed shortage was mentioned frequently, for almost all legume species, due to lack of money and/or limited seed availability. Seed shortages in legumes may be exacerbated due to the high level of food insecurity reported (41%), which is expected to put pressure on seed saved due to home consumption of legume grain. Post-harvest storage was an issue with specific varieties, as has been noted in previous studies[62]; for example, varieties that are high in oil are susceptible to spoilage; however, this characteristic may enhance nutrition value.

Farmers reported several challenges specific to growing pigeon pea, including the range of field pests as well as its susceptibility to post-harvest weevil damage. The main field pest is the pollen beetle, which feeds on the plant's floral parts, resulting in low fertilization, pod set and grain yield[63]. According to farmers, the ideal variety of pigeon pea should be early maturing, in order to avoid certain pests and provide soil fertility benefits.

Farmers reported that most legumes were tolerant of low-fertility soils, with the exception of soybean which did

not generally perform well. Improved growth and grain yield for soybean was high priority (Table 5). The soybean varieties grown are not generally promiscuous types and require rhizobium inoculum—which is not available commercially in Malawi—and soils in this area may not have sufficient presence of the appropriate rhizobium species to support BNF in this newly introduced crop[64]. Similar concerns have been reported in southern Malawi for velvet bean and pigeon pea[65]. Applying fertilizer to low-nutrient soils may improve soybean yield; in another study in northern Malawi, application of 23:20:4 and 46:40:8 kg ha^{-1} of N:P:S fertilizer increased grain yield of soybean by 27 and 71%, respectively, over the control[17].

Sustainable farming relies on biologically mediated nutrient acquisition, most notably BNF. However, in our study, farmers allocated twice as much field space for maize crops as they did for legumes (0.35 versus 0.15 ha), consistent with earlier findings in central and southern Malawi where the land allocated to maize was 3–9 times larger than groundnut fields[23]. If N inputs are to be substantial, then the proportion of land devoted to legumes must also be substantial[15]. Another way to enhance BNF is to give priority to long-lived legumes, shrubs and vines that grow and fix N over most of the year rather than only 4–6 months as is typical of annuals[18]. The farmer preference for edible legumes such as soybean and groundnut presents a challenge, as there is a trade-off between maximizing grain yield and maximizing vegetation that contributes to soil fertility[8]; however, legume–legume intercrops of different growth types may be an important way forward to address dual aims.

Conclusions

Legumes offer an important means of improving food security and the sustainability of maize-based cropping, but there are many challenges, including limited seed access, low soil phosphorus status and limited area devoted to growing legumes. Farmers are interested in expanding areas devoted to legume production, but there are barriers to wider adoption and scaling up. Most of the challenges are socio-economic, including seed access, labor and markets. Improved legume seed is expensive and hence not affordable for many smallholder farmers, and there is considerable need for the government, NGOs and communities to identify strategies to improve seed availability for smallholder farmers.

Legume adoption and residue incorporation are limited across SSA[23], but nutrition education, introduction of new legume species, and on-farm experimentation through participatory research and extension conducted by the SFHC project have increased legume adoption and residue incorporation in these northern Malawi communities. Farmers expressed interest in experimenting with legumes and in education about agronomy, pest control and nutrition, suggesting many opportunities for wider legume adoption. In agronomic practices, farmers were particularly interested in planting time, patterns and density of sole and intercropped legume, and identification and control of pests and diseases. Interest in grain utilization was also a major area of interest, where recipes and nutrition education could support not only nutritional gains, but also expanded BNF through promoting legume adoption.

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Soil quality improvement under an ecologically based farming system in northwest Missouri

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Abstract

Ecologically based farming conserves and improves the soil resource and protects environmental quality by using organic or natural resources without the application of synthetic chemicals. Soil quality assessment indicates the ability of management systems to optimize soil productivity and to maintain its structural and biological integrity. Our objective was to evaluate the effect of ecologically based management on biochemical characteristics of soil [soil quality indicators (SQI)] as an assessment of soil quality. The study was conducted on an ecologically based farming enterprise established on gently sloping soils of Sharpsburg silt loam (fine montmorillonitic, mesic Typic Argiudolls) in Clay County, Missouri, which was previously under conventional corn and soybean production. The transition to organic farming began in 1995, which included a primary management strategy to restore soil organic matter consisting of the establishment of native prairie plants and the application of composted vegetative residues and litter from horse and laying hen operations. Soils were collected at 0–10 cm depths from sites under organic production (orchard and vegetable), managed prairie/pasture and from adjacent unmanaged fields during 2003–2008 for soil quality assessment. Soil organic carbon (SOC) and water-stable soil aggregates were considerably increased by up to 60 and 72%, respectively, in organic production sites compared with tilled cropland by the fifth year of assessment. Organically managed systems and restored prairie sites significantly increased ($P < 0.05$) soil enzyme activities compared with unmanaged grass and tilled cropland. For example, dehydrogenase and glucosaminidase activities increased by 60 and 73%, respectively, under organic vegetables compared with tilled cropland. Soil enzyme activities were significantly correlated with SOC content (r values up to 0.90, $P < 0.001$). The results of the soil quality assessment suggest that ecologically based management successfully restored biological activity of silt loam soils previously under intensive conventional agriculture. The system practiced at the study sites illustrates how resources internal to the farm (i.e., composts) can be used to manage soil productivity.

Key words: agroecosystems, ecosystem restoration, ecosystem services, microbial activity, organic farming, soil aggregate stability, soil enzymes, soil quality

Introduction

Ecologically based farming systems, or ecological agriculture, purposely manage biological processes at multiple scales—from the rhizosphere to the soil environment, and from field scale to the watershed level[1,2]. These systems are inherently multifunctional because they provide many different ecosystem services or functions to crop and livestock production; air, soil and water quality maintenance; preservation of biological diversity and promotion of human health[3]. Ecologically based farming systems, similarly described for organic management systems[4,5], inherently manage the distribution and intensity of ecosystem disturbance through reduced tillage to increase soil microbial diversity, soil organic matter and nutrient cycling; maintain biological diversity; and provide complexity to agricultural systems for strong ecological networks through the establishment of cover crops, strip-cropping, filter strips and 'non-crop' landscapes including grasslands and woodlots. The non-crop landscapes are maintained to provide vital habitats for beneficial organisms that overwinter and prey on weed seeds and support flowering plants in adjacent crop production areas. The integration of these natural landscapes into agricultural production systems can sustain the environment by serving as nutrient sinks to capture

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soluble nutrients and as traps for potential xenobiotic contaminants before these impact aquatic ecosystems[1,6].

To ensure ecologically based practices are beneficial to soil functioning and environmental quality, soil quality assessment can be used to provide the information needed to evaluate the impact of implementing these management systems[7]. The soil quality concept generally encompasses the basic components of physical, chemical and biological properties of soils within its description as the capacity of a specific soil to function under a natural or managed condition to sustain biological productivity, promote plant and animal productivity, and maintain environmental quality[8–10]. Soil health, viewed within the context of soil quality, considers soil as a vital living system to provide sustainability of the soil quality functions, based primarily on ecological characteristics and associated with biological diversity and ecosystem stability[8,9]. Thus, soil health may be a more appropriate expression for assessment of soil management under ecologically based farming practices as organic management seeks to enhance soil biological activity to achieve improved nutrient cycling, plant growth promotion, disease suppression and resilience to environmental stress[6,9]. However, the assessment of soil health can be accommodated through use of soil quality indicators (SQI). Soil quality assessment involves measurement of multiple soil properties representing chemical, physical and biological characteristics. Selection of SQI is dependent on soil characteristics, environmental influences, land use and management goals, and environmental protection[11]. For ecological agricultural systems, a suite of SQI including aggregate stability, soil organic C and total N, and enzyme activities reliably detect responses after transition to and establishment of ecologically based management practices[12]. Further, a better understanding of overall microbial activity and C dynamics in these agroecosystems will contribute to estimates of environmental and economic benefits, and aid policy and management decisions for these systems[13].

Several studies have examined biological SQI in low-input and organic farming systems, most of which are compared with similar soils and/or crops under 'conventional management'[14–17]. Improved soil quality inferred from increases in soil organic matter for soils under ecological or organic management is widely reported and reflects the integration of perennial grasses, cover cropping in crop rotations and incorporation of organic amendments (crop residues, manures and composts) into soils[4]. High microbial activity indicated by soil enzyme activities and CO_2 evolution in organic systems contribute to improved resource utilization and enhanced soil fertility[18]. The concurrent increased microbial density and diversity and biological activity in organically managed soils are largely driven by the increases in soil organic matter. Organic C is widely considered the most important governing factor in soil quality interrelationships[19] that are expressed in improved biological activities, plant available nutrients and functional soil structure, including high aggregate stability and low bulk density[20,21]. Little or no information is available on soil quality characteristics of the multiple landscape and production components that are integral to an ecologically based farming system. As ecological agriculture functions through interrelationships among soil–plant–animal–environmental components, soil quality assessment can be a useful tool in describing these interactions. Our objective was to evaluate the effect of ecologically based management on selected biochemical, chemical and physical characteristics of soil (SQI) as an assessment of soil quality during transition to organic production on previously tilled cropland. Our hypothesis was that the soil quality of previously intensively tilled cropland can be improved using ecologically based practices of organic amendments and integration of perennial vegetation. The results were collected during a 6-year study conducted at Prairie Birthday Farm (PBF), an ecologically based farm in northwest Missouri. A previous report described the ecosystem restoration process and the integrated food-producing enterprise at this farm[22].

Materials and Methods

Site description, basic management practices and soil analyses

PBF is located on the dry-mesic loess/glacial till prairie landscape[23] in Clay County, Missouri, USA (39°20′N, 94°24′W). The deep loess soils on the farm are comprised of Sharpsburg silt loam (fine, montmorillonitic and mesic Typic Argiudolls) situated on the summit and 3–10% slopes of shoulder landscape positions, which are mapped as an 'eroded soil phase'[24]. Previous row-cropped maize (*Zea mays*) and soybean (*Glycine max*) likely contributed to erosion, which resulted in shallow topsoil depths of $\leqslant 5$ cm on shoulder to about 20 cm on summit landscape positions.

A diverse production system including native prairie plants, heirloom fruit trees, vegetables, herbs, pastured heritage chickens and rotation paddock horse pastures was established at PBF in 1993. 'Corral compost' is prepared on-farm from mixtures of horse manure, chicken manure + hydrated lime, mixed hardwood sawdust and shavings; and is mixed/aerated in the barn lot by trampling of the horses (Table 1). Compost is applied at rates of 28 Mg ha^{-1} (5.3 Mg C ha^{-1}) around fruit trees in the orchard and 14 Mg ha^{-1} (2.6 Mg C ha^{-1}) soil-incorporated in vegetable plots. Other management practice details regarding crop rotation and tillage in vegetable sites pest management, pruning and harvest schedules for blueberry, table grape and tree fruit; and vegetative composition and burning schedule for the restored prairie are reported in Hezel and Kremer[22]. The reference sites were assessed only to gauge progress in expected soil-quality changes due to the establishment of ecological

Table 1. Various properties of compost prepared on-site at PBF, 2005–2008.

Property	Range of values
pH	7.0–7.6
EC (1:1, solid:water suspension)	5.5–6.0 dS m^{-1}
Total C	18.65–20.2 g kg^{-1}
Total N	1.25–1.30 g kg^{-1}
C:N ratio	14.9–15.5
Total P	4.5–5.0 g kg^{-1}
Total K	8.9–10.1 g kg^{-1}
Total Ca	20–23.5 g kg^{-1}
Total Mg	2.5–4.5 g kg^{-1}
Total Zn	130–142 mg kg^{-1}
Total Fe	6300–6600 mg kg^{-1}
Total Mn	743–760 mg kg^{-1}
Total Cu	30–35 mg kg^{-1}
Moisture	400–500 g kg^{-1}
Dehydrogenase activity	50–127 μg TPF g^{-1}
Glucosaminidase activity	490–550 μg PNP g^{-1}
FDA hydrolase activity	600–750 μg fluorescein g^{-1}

Random samples collected at least once annually during a 4-year period from available compost applied during a single year; thus data represent different batches prepared in different years rather than composite samples.
FDA, fluorescein diacetate.

management, differing primarily in tillage and organic amendment, on a similar landscape. These sites included adjacent unmanaged grass and hay fields (no inputs, forage harvested at least once annually) and a conventionally managed field rotationally cropped for corn and soybean (glyphosate-resistant varieties managed according to standard fertilizer and pesticide recommendations[25]) initially assessed in 2005 and 2007, respectively. Soil chemical properties were variable with pH ranging from 5.7 to 6.9, soil organic matter content of topsoil from 3.0 to 6.0%, and phosphorus and potassium contents of 23–345 and 130–760 kg ha^{-1}, respectively. Total annual precipitation averages 920 mm; temperatures range from −14 to 30°C, with an average summer temperature of 25°C[23].

Annual soil sample collection for soil quality analyses was conducted between June 15 and July 15 during 2003–2008. Soils were collected to a 10-cm depth using a stainless steel probe that removed a 3.8 cm diameter core. The soil samples were collected following transects established across the landscape within the restored prairie and managed pasture. For the smaller areas on which vegetable plot, tree fruit orchard (TFO), blueberry and table grape production were situated, soils were collected from three randomly assigned points within each production area. The reference sites within the same landscape and soil association were also sampled and included: (1) an adjacent fallow, non-grazed grass field (sampled 2005–2008); and (2) an adjacent field under long-term traditional cultivation for ⩾17 years (sampled in 2007 and 2008 only). Two soil cores were collected at three random points along each transect (restored prairie, managed pasture and reference sites) or within production areas and composited for each point. Soils were transported in a cooler at ambient soil temperature to the laboratory, passed through a 7-mm mesh sieve and stored in plastic bags at 4°C prior to analyses.

Total nitrogen (TN) and soil organic carbon (SOC) contents of each soil sample were determined, beginning in 2003, by dry combustion at 900°C using a LECO Tru-Spec C/N analyzer (LECO Corp., St. Joseph, MI)[26]. Water-stable aggregates (WSA) were determined on 10-g air-dried soil samples using the wet-sieving method[27,28]. Soil samples were spread on a 250-μm sieve, placed on the wet-sieving apparatus and subjected to periodic immersion in water (30 vertical strokes per minute for 10 min). Soil particles that passed through the sieve were considered the fraction that was unstable in water. Soil remaining on the sieve was dried at 105°C, weighed and dispersed with 50 ml of 0.5% sodium hexa-metaphosphate to separate water-stable soil fractions from coarse particles. Coarse particles were collected, dried and weighed. The proportion of WSA was calculated as a percentage of the weight of the stable fraction of the total soil weight.

Soil microbial activity was represented as the activity determined for selected soil enzymes. Dehydrogenase activity based on reduction of the substrate triphenyltetrazolium chloride (TTC) was used to estimate respiratory activity for viable soil micro-organisms[29]. Soil (6 g, fresh weight) was incubated in 1.0 ml of 3% TTC and 3.0 ml of 0.2 M $CaCO_3$ for 24 h at 37°C. Reactions were terminated by adding 50 ml of methanol and extracted 30 min on a rotary shaker. Reaction mixtures were filtered, the concentration of the product, 2,3,4-triphenyl-tetrazolium formazan (TPF) was determined spectrophotometrically at 485 nm, and the enzyme activity expressed as μg TPF released g^{-1} dry soil h^{-1}.

β-Glucosaminidase activity, representative of nitrogen mineralization, was determined by incubating 1-g soil samples with *p*-nitrophenyl-*N*-acetyl-β-D-glucosaminide substrate for 1 h at 37°C[30]. After incubation, reaction mixtures were filtered and the concentration of the product, with *p*-nitrophenol (PNP), was determined spectrophotometrically at 405 nm and the enzyme activity expressed as μg PNP released g^{-1} dry soil h^{-1}.

Fluorescein diacetate (FDA) hydrolysis was determined based on the Schnürer and Roswall method[31] with modifications[32]. FDA is a general substrate and represents the overall activity of microbial enzymes in soil belonging to the broad classes of esterases, lipases and proteases[33]. FDA hydrolytic activity was detected by spectrophotometrically measuring the product of hydrolysis (fluorescein). The assay consisted of suspending 1.0 g soil in 20 ml of phosphate buffer (pH 7.6), shaking for 15 min, and adding 100 μl of FDA (4.8 mM). The assay mixture was placed on a rotary shaker at 100 rpm and incubated at 30°C for 105 min. The assay was terminated by extraction with acetone (10 ml) followed by filtration through filter paper (Whatman No. 2).

Absorbance of each filtrate was measured at 490 nm and the total amount of product formed was calculated based on a regression equation generated from standards of known fluorescein concentration; the enzyme activity was expressed as μg fluorescein produced g^{-1} dry soil h^{-1}.

Experimental design and statistical analyses

As the study was an on-farm experiment, blocks for sampling were established within each production system. Data were analyzed assuming a completely randomized design with eight production systems and six sample years with three replications (blocks). Analysis of variance was conducted to test differences between production systems and year of sampling and to test for homogeneity among SQI parameters. Fisher's protected least significant difference (LSD) was calculated to find significant differences for each measured parameter with significance considered at $\alpha = 0.05$. Pearson correlation coefficients were calculated for pairs of soil enzyme and other soil properties including SOC and WSA, and regression models were derived to predict soil enzyme activity using the soil property.

Results

Soil carbon and nitrogen

Both SOC and TN differed between the production and managed pasture sites compared with the unimproved cool season grass and continuous cropping sites. By the sixth year of assessment (2008), SOC and TN were higher in all production sites by up to 60 and 78%, respectively, compared to unmanaged grass fields, likely due to annual addition of compost and mulch to production sites or horse manure deposition in the managed pasture (Figs. 1 and 2). Accumulation of SOC and TN under restored native prairie was significantly lower compared with other managed sites, reflecting the longer establishment period for warm season grasses and forbs, and the highly degraded initial soil condition ($\leqslant$ 2 cm topsoil) on which the native plantings were established. Soil organic C increased in the restored prairie by about 10% compared to the first year of the assessment period; however, the last-measured C values were still 46% higher than that found for the continuous crop site. The C and N increases also reflected a gradual decrease in soil C:N ratios (not shown) within the managed production systems.

Aggregate stability

The trends for annual increase for WSA (Fig. 3) in the restored prairie and managed pasture suggested that an effective sink developed for stabilizing the increased C and N inputs from perennial vegetation as their root systems developed and established within the soil profile. However, inconsistent increases in WSA in soil under

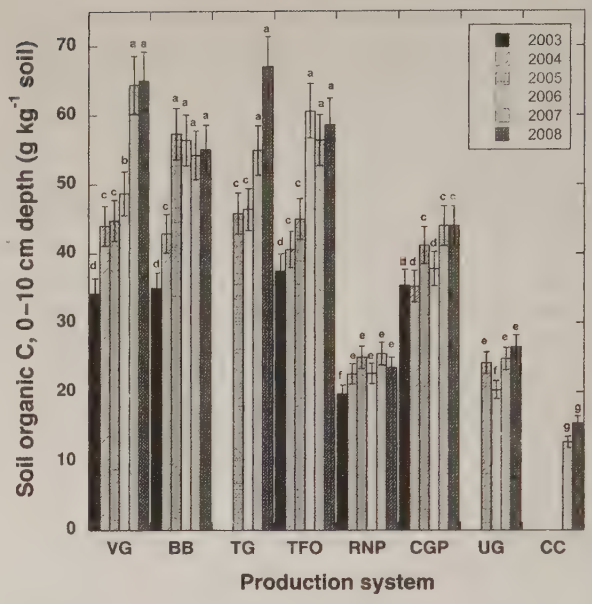

Figure 1. SOC in surface 10 cm of soils under various management systems in an ecologically based farming system, Clay County, Missouri, 2003–2008. Different letters indicate Fisher's LSD at significance level $P < 0.05$; standard error bars for the mean in each year × production system are also shown. Management systems: VG, vegetable; BB, blueberry; TG, table grapes; TFO, tree fruit orchard; RNP, restored native prairie; CGP, cool season grass pasture; UG, unmanaged grassland; CC, continuously cultivated row crops (maize–soybean rotation).

vegetable and blueberry production (about 25% WSA for vegetable compared with 58% for prairie by 2008) may reflect the disturbance effects of tillage used in these intensively managed crops. The gradual increase in WSA under grapes at 5 years after assessment began may be due to the use of various mulches in addition to compost without soil disturbance that contributed to aggregate formation; similarly, increased WSA in TFO soils was a result of the establishment and development of the permanent, native plant vegetation in the alleys, likely a result of continuous root biomass development in the upper soil profile. Low WSA (< 20%) for the cultivated check soil illustrates the impact of losses of C and soil structure during prolonged intensive agricultural operations including tillage, minimal crop residue retention and no provision for winter vegetative cover.

Soil enzyme activities

The predominant trend found in this long-term study was for increasing soil enzyme activities in all managed prairie/pasture and production systems over time compared with the unimproved cool season grass and continuous cropping sites. The highest activities within the production sites were achieved and sustained within 2–3 years after the onset of assessment. For example,

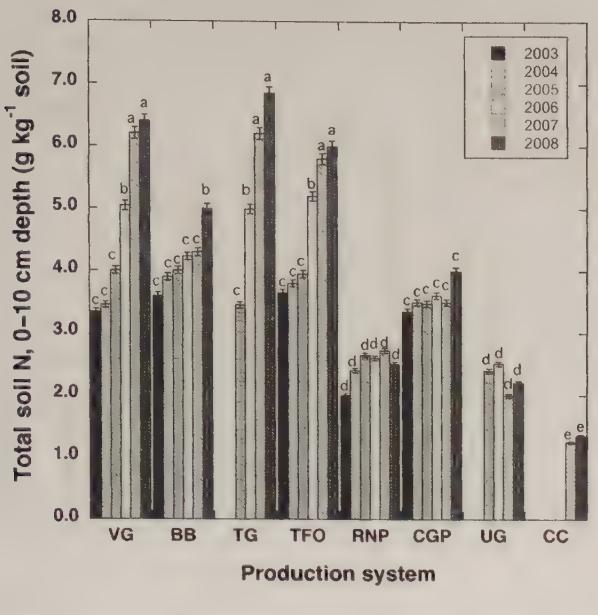

Figure 2. TN in surface 10 cm of soils under various management systems in an ecologically based farming system, Clay County, Missouri, 2003–2008. Different letters indicate Fisher's LSD at significance level $P<0.05$; standard error bars for the mean in each year × production system are also shown. Management systems: VG, vegetable; BB, blueberry; TG, table grapes; TFO, tree fruit orchard; RNP, restored native prairie; CGP, cool season grass pasture; UG, unmanaged grassland; CC, continuously cultivated row crops (maize–soybean rotation).

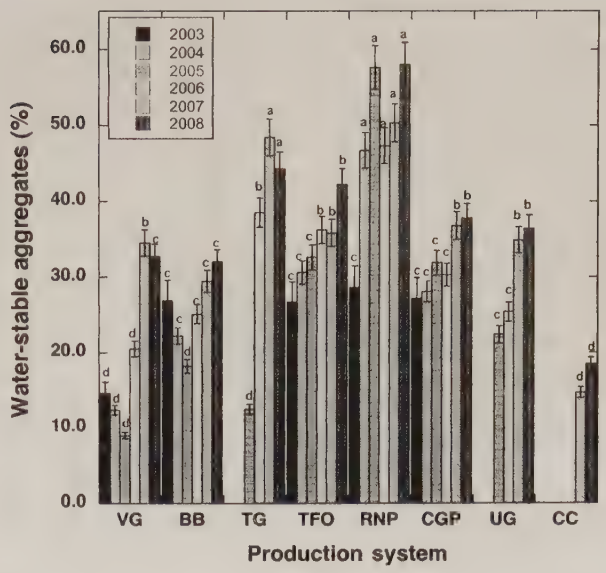

Figure 3. WSA developed in surface 10 cm of soils under various management systems in an ecologically based farming system, Clay County, Missouri, 2003–2008. Different letters indicate Fisher's LSD at significance level $P<0.05$; standard error bars for the mean in each year × production system are also shown. Management systems: VG, vegetable; BB, blueberry; TG, table grapes; TFO, tree fruit orchard; RNP, restored native prairie; CGP, cool season grass pasture; UG, unmanaged grassland; CC, continuously cultivated row crops (maize–soybean rotation).

soil dehydrogenase attained high activity levels in the vegetable and grape production sites and in the restored prairie and managed pasture sites by 2006 (Fig. 4). The activity levels in unmanaged grass and continuous cultivated sites were 58 and 78% lower, respectively, compared with soil dehydrogenase measured in the same year for ecologically managed sites. Trends in β-glucosaminidase activity were similar to dehydrogenase activity but demonstrated more similarity among all production and managed sites within years (Fig. 5). Also, β-glucosaminidase activity increased significantly ($P<0.05$) for all managed sites by the end of the assessment period and was lower in unmanaged grass and continuous cultivated soils at about the same magnitude as for dehydrogenase. Highest soil FDA activities were detected for vegetable, blueberry and table grape production sites; intermediate levels were found for the TFO, managed prairie and pasture sites; and the lowest levels were exhibited in soils from unmanaged grass and continuous cultivated sites (Fig. 6).

Pearson's correlations between enzyme activities and SOC were strong (i.e., $r^2=0.62$ for glucosaminidase; 0.91 for FDA hydrolase) across all treatments; however, the enzyme activities were poorly correlated with WSA possibly due to the adverse effects of tillage required to incorporate organic amendments in some production sites.

Discussion

Since transition of the previous conventional farm to an organic system began 14 years ago, all organic management systems followed at PBF have improved the Sharpsburg silt loam in organic-matter content, water-stable aggregation and soil biological activity, including a critical increase in potential N-mineralizing activity. Although water-stable aggregation is somewhat lower at sites receiving composts that are incorporated in soil, the activity and quality of the organic matter developed in place is considerably higher compared with conventional, unmanaged sites within the same landscape. Even though aggregation is relatively high under the unmanaged grasses, the lower microbial activity detected suggests considerably lower soil health resulting from continuous poor management. The differences in enzyme activities between the specific sites are likely due to differences in microbial community structure, substrate characteristics and availability, or soil moisture resulting in spatially variable soil chemical and physical properties. Similar confounding effects on soil microbial function have been reported for alternative soil management compared with crop monocultures[34]. Furthermore, microbial activity in production sites receiving on-farm compost applications was likely stimulated by readily available nutrients contained within the compost (Table 1), analyses of

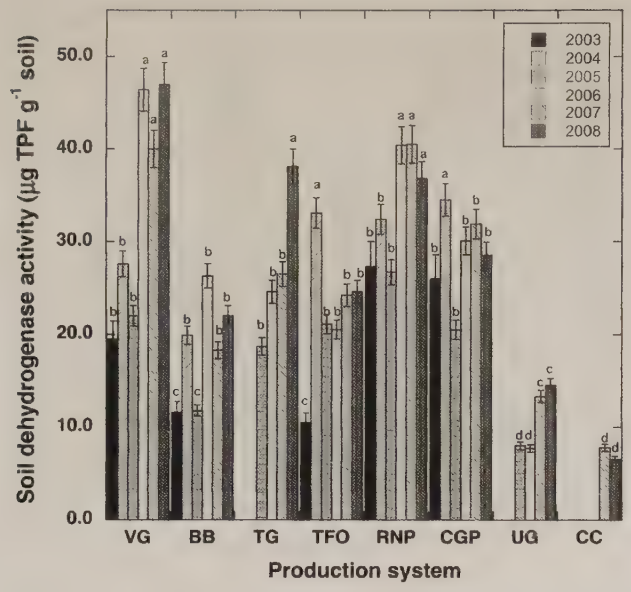

Figure 4. Soil dehydrogenase activity in surface 10 cm of soils under various management systems in an ecologically based farming system, Clay County, Missouri, 2003–2008. Different letters indicate Fisher's LSD at significance level $P<0.05$; standard error bars for the mean in each year × production system are also shown. Management systems: VG, vegetable; BB, blueberry; TG, table grapes; TFO, tree fruit orchard; RNP, restored native prairie; CGP, cool season grass pasture; UG, unmanaged grassland; CC, continuously cultivated row crops (maize–soybean rotation). TPF, triphenyl formazam product for quantifying dehydrogenase activity.

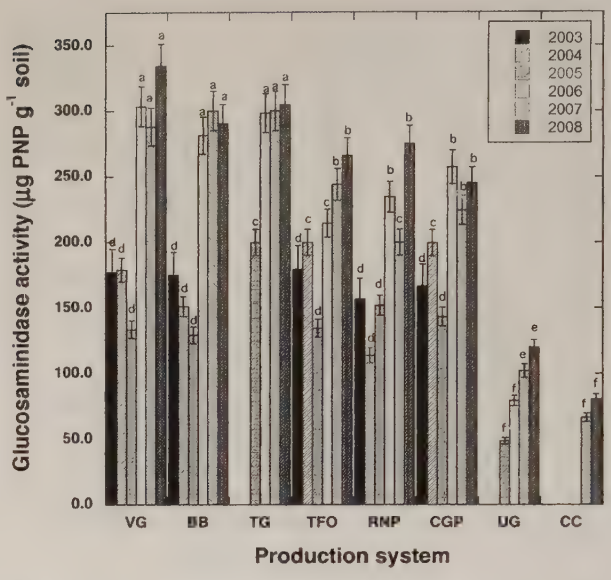

Figure 5. Soil glucosaminidase activity in surface 10 cm of soils under various management systems in an ecologically based farming system, Clay County, Missouri, 2003–2008. Different letters indicate Fisher's LSD at significance level $P<0.05$; standard error bars for the mean in each year × production system are also shown. Management systems: VG, vegetable; BB, blueberry; TG, table grapes; TFO, tree fruit orchard; RNP, restored native prairie; CGP, cool season grass pasture; UG, unmanaged grassland; CC, continuously cultivated row crops (maize–soybean rotation). PNP, *p*-nitrophenol product for quantifying glucosaminidase activity.

which compared very favorably with nutrient-sufficiency levels for composts acceptable as soil amendments[35,36]. We also found very high activities of selected enzymes in the compost (Table 1), which suggested that a highly active beneficial microbial component, or perhaps the enzymes themselves in free or immobilized forms within the compost materials[37], were added to soil and supplemented indigenous soil microbial diversity and activity[38].

Annual soil quality assessments since 2003 demonstrated that SOC has consistently increased under organic management compared with conventionally managed soils, leading to improved soil fertility and plant productivity. The prairie site is gradually increasing in SOC, even though the shoulder landscape position was severely eroded leaving very shallow topsoil layers in which SOC could develop and be retained. The high SOC ($\approx 40\,g\,kg^{-1}$) in pasture sites reflects the benefit of integrating livestock in this system. Very high SOC contents in orchard, vegetable, blueberry and grape plots (40–$65\,g\,kg^{-1}$) are the result of annual applications of high-quality compost produced on the farm. Increased soil-aggregate stability was associated with long-term organic management, reflecting improved soil aeration, water availability and increased microbial activity. The highest aggregate stability in the prairie site (50–60% stable aggregates) exhibits characteristics of soils supporting undisturbed root systems of established perennial grasses. The aggregate stability of pasture and orchard sites was intermediate ($\approx$30%), demonstrating the contribution of the relatively high SOC as well as the recently established grasses. Aggregate stability under vegetable production only exceeded 20% during the last 2 years of the survey, yet this site exhibited some of the highest enzyme activities and SOC contents. The contrast in levels of SQI due to tillage required in this production system did not offset the overall increase in soil quality, similar to previous studies in which the incorporation of cow manure and clover green manure with light tillage provided higher soil quality than a conventional no-till system[39]. Unmanaged pasture and hay field sites revealed generally high WSA due to long-term cool-season grass stands and no recent cultivation.

A high WSA percentage indicates excellent soil structure, low erosion potential, good water infiltration and high microbial activity. Previous studies on grassland ecosystems and sustainable agricultural systems have demonstrated the value of high WSA (40–70%) in contributing to increased soil organic C and N and enhancing soil microbial processes measured as soil enzyme activities[40]. Similarly, stable aggregation, most prevalent in soils with a high density of roots developed from

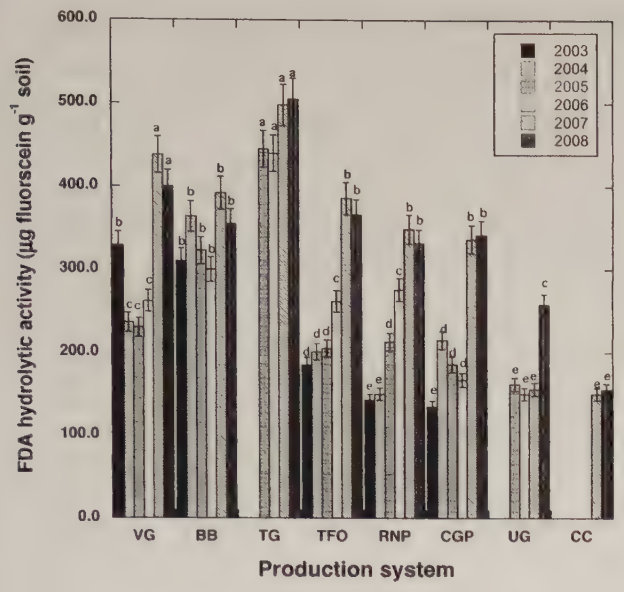

Figure 6. Soil FDA hydrolysis activity in surface 10 cm of soils under various management systems in an ecologically based farming system, Clay County, Missouri, 2003–2008. Different letters indicate Fisher's LSD at significance level $P<0.05$; standard error bars for the mean in each year × production system are also shown. Management systems: VG, vegetable; BB, blueberry; TG, table grapes; TFO, tree fruit orchard; RNP, restored native prairie; CGP, cool season grass pasture; UG, unmanaged grassland; CC, continuously cultivated row crops (maize–soybean rotation).

long-term presence of vegetative cover, provided the greatest amounts of organic carbon for aggregate formation[41]. Improvement in WSA therefore suggests that the soil structure and C were restored on eroded soils through organic inputs associated with the sustainable management practiced at PBF. It is noteworthy that the establishment and maintenance of restored prairie on the severely eroded landscape at PBF increased SOC and WSA two and three times, respectively, compared with the adjacent continuously row-cropped site, confirming the significant impact of perennial grassland on soil quality improvement following conversion from tilled cropland[42,43].

High potential soil enzyme activities at all organically managed sites demonstrated the impact of systematic amendment of organic materials on the overall improvement of soil health. This coincides with previous conclusions that soil amendments, including animal and green manures, and plant diversity (perennial mixed covers and rotations) are important in maintaining soil microbial activity compared with conventional conservation tillage practices where the repeated applications of inorganic fertilizers suppress production of certain soil enzymes critical in cycling of certain nutrients[42]. Amendment with compost (pH $\geqslant$ 7.0; Table 1) likely aided in maintaining organically managed sites for overall higher microbial activity relative to the unmanaged grass and tilled cropland sites in which soil pH was <5.5. Consistent trends in higher activity of all enzymes assayed in this study validate these as excellent indicators of management-induced changes in soil quality[44]. Microbial dehydrogenase activity (Fig. 4) was significantly higher in soils receiving organic inputs relative to unmanaged or conventionally managed soils. This enzyme, representative of the viable soil microbial community, organic matter decomposition, plant growth promotion and potential plant disease suppression, has frequently been shown to increase under organically managed crops and soils by up to 10 times compared with conventionally managed soils[42,45].

Nitrogen-mineralizing enzyme activity indicates release of nitrogen (ammonium and nitrate) from organic substances during decomposition by soil micro-organisms. As PBF soils have been amended with organic materials, populations of N-mineralizing micro-organisms were high and very active, thus few differences are seen among organic treatments. However, organic sites provided 5–6 times the N-mineralization potential compared with conventional sites; these extreme differences demonstrate the N-enhancing benefit to soil of organic management. Soil glucosaminidase activity (Fig. 5) indicates mineralization of N from complex organic substances comprising composts and manures, root tissue and exudates, and dead microbial biomass, eventually becoming available for plant uptake[30,46,47]. Similarly, FDA hydrolytic activity was generally high in soils of the managed pasture/prairie and production sites (Fig. 6). Previous studies also show that FDA hydrolytic activity is an adequate indicator of improved soil quality under managed perennial grass ecosystems[48] and native forest[49]. The close relationship of SOC and soil microbial activity is consistent with previous studies reporting that while SOC levels indicate the productivity or potential sustainability of a specific agricultural soil, when it is combined with appropriate biological, physical and chemical properties, the impacts of both short- and long-term management on soil quality are evident[50]. It has been further suggested that high levels of organic inputs, as practiced at PBF, contribute to increased microbial abundance and genetic diversity, leading to greater functional diversity and higher metabolic activity (soil enzyme activity) in organic or ecologically managed farming systems[45].

Conclusions

The organic process practiced at PBF and sustained over a 16-year period clearly demonstrates how regular amendment with organic materials can improve several aspects of soil health, including increased soil organic matter, improved structure (aggregate stability), and increased microbial activity that contributed to a high potential for mobilizing organic N for optimum plant growth and

productivity. The resources internal to the farm (i.e., composts) are used to restore soil quality on organic matter-depleted and eroded soils, resulting from degradation by previous continuous cultivation. Further, perennial systems that include native prairie plants illustrate organic matter 'grown in-place'[35] for improving the properties of soils previously subject to severe erosion and for improving production in perennial horticultural systems (i.e., orchards). Organic growers might readily adapt some or all of the strategies described for the PBF system to improve soil health and crop productivity in other enterprises. It is possible that high soil quality developed under organic management contributes to higher quality fruits and vegetables, as suggested by a recent report on higher quality strawberries produced on high-quality soils under organic management compared with their conventional counterparts[51]. Correlation of soil quality with fruit quality is a current research focus at PBF for subsequent publication.

Soil properties and productivity, represented by improved nutrient cycling, will likely be maintained or improved during the organic transition management that includes scheduled addition of organic amendments consisting of on-farm produced composts and mulches; the restored native prairie will continue to improve soil quality while also providing habitats for beneficial insects and pollinators for the production enterprises on the farm. In addition, the continuous vegetative cover in the prairie, pasture and orchard alleys reduces or eliminates the need for synthetic pest-management chemicals and provides bee-foraging habitats. Finally, the soil quality assessment conducted in this study demonstrated that an ecologically based farming system integrating perennial vegetation with fruit and vegetable sites offers an effective management system for optimizing horticultural crop production while promoting soil conservation. All SQI used were sensitive in detecting soil-property changes as a result of ecologically based management, and allowed interpretation related to the type, magnitude and consequences of altered ecosystem processes. The results of our long-term study have important implications for understanding how ecologically based management practices can enhance soil biological and biochemical processes, to improve the overall soil quality and promote the production of horticultural crops without synthetic chemical inputs, and improve environmental quality.

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International trade of organic food: Evidence of US imports

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Abstract

Over the past decade, organic food sales and farmland have grown rapidly worldwide. As the US market for organic food has expanded, anecdotal evidence indicates that imports of organic food have increased. US organic handlers may be importing to meet consumer demand for out-of-season products, as well as products not grown domestically. Handlers may also be importing organic products that are in short supply or to reduce input costs. This paper provides the first examination of imports of organic products into the USA. Data from a national survey of certified organic handlers in 2007 are used to examine the extent, types and origins of imported organic commodities. A Heckman model is employed to investigate the factors that influence an organic handler's decision to import organic products, and the level at which organic handlers import a product. Summary results show that while many of the products being imported into the USA are those that cannot be produced domestically, such as coffee and tropical fruits, some oft-imported commodities are those that can be produced in the USA, such as soybeans, wheat, barley and berries. The summary results also show that organic handlers are procuring almost a half of their imported products from a few countries, including Canada, China, Mexico, Brazil and Indonesia. In the econometric analysis, we found those handlers prioritizing local suppliers negatively affected the facility's decision to import products. The use of a social label, such as Fair Trade, positively affected a handler's decision to import. The size of organic sales was important to both the decision to import and the share imported, with larger firms more likely to import and smaller firms less likely to import. However, once a smaller firm had decided to import, they imported a larger share. Finally, our analysis found that experiencing limited supplies or prioritizing price with suppliers did not influence a handler's decision to import products. Based on the findings, we suggest future research avenues, including studies that address consumer preferences and the impact of increased imports on domestic organic farms.

Key words: organic food, imports, handlers, Heckman model, consumers, producers

Introduction and Context

Despite economic problems worldwide over the past few years, organic food sales have expanded over the past decade, reaching almost US$60 billion in 2010, up from US$25 billion in 2003[1,2]. Historically, the vast majority of organic sales were made in the USA and Europe. Although this is still true, markets for organic products are growing in many other countries[1]. At the same time, support of organic agriculture in developing countries by international organizations and assistance through monetary aid has also expanded[3]. As a result, organic farmland and the number of organic farms across the globe have increased quickly. Approximately one-third of the world's organic land and 80% of its organic producers are now in the developing and emerging markets[1]. Many of these countries are targeting the USA and the European Union (EU) as fertile export markets for their organic products.

Anecdotal evidence suggests that imports of organic products into the USA have increased over the past decade. The implementation of the National Organic Standards in 2002, and more recent policy changes, such as the completion of an organic trade equivalency agreement with Canada and the EU, have served to enhance the ability of the industry to import and export organic products. Organic handlers (manufacturers, brokers, processors, and packers and shippers certified to handle organic products in accordance with the National Organic Standards) are the main importers of organic products. As they are situated in the middle of the organic supply chain—procuring from farmers and other

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suppliers and selling to retailers and other outlets—the decision to import products made by organic handlers can be affected by changes in demand *vis-à-vis* transactions with retailers (and ultimately their consumers) and supply through transactions with farmers.

For organic handlers, there are many competing consumer and producer interests influencing the decision to import organic products. The US market for organic products has expanded rapidly over the past decade, with sales reaching US$22.3 billion in 2009[4]. As the organic industry has grown, some organic firms have developed international supply chains to satisfy consumer demand for off-season organic produce (such as grapes produced in Chile during the US winter months), as well as for products grown primarily outside the USA, such as tropical fruits, coffee, tea and cocoa.

At the same time as many consumers have demanded an increasing array and quantity of organic products, some consumers have not been welcoming imports of organic food. While most research has suggested that consumers purchasing organic products are interested in the health, food quality or environmental aspects of organic food[5], a segment of organic consumers is strongly interested in supporting local or regional farmers. Some consumers feel that purchasing products from producers abroad, along with the environmental costs incurred in transporting imported products over thousands of miles[6,7], is counter to the intentions of organic production. In other cases, consumers and advocacy groups may be wary that inspection and regulation in other countries (such as China) is lax compared to those in the USA, even if the farms must be inspected by a third-party certifier regulated by the US government[8]. Other recent information[9] and incidents, such as a fraudulent National Organic Program organic certificate produced by an uncertified operation in China (for soybean, millet and buckwheat)[10], are related to these rising concerns.

Retailers have taken notice of the consumer objections toward imported organic foods in the USA, particularly those products raised in China. Trader Joe's, for example, discontinued selling both organic and non-organic single ingredient foods, such as garlic, frozen organic spinach and edamame, produced in China based on consumer concerns[11], while Whole Foods limited their imports of organic products from the country for the same reason[12]. A recent study of US food retailers selling organic food found that 29% of those importing organic products for sale discontinued an imported organic product because of customer complaints about the geographic origin of the produce. The vast majority of those customer complaints were about imports of organic products from China[13].

The domestic supply of organic products can also influence a handlers' decision to import organic products. Adoption of organic agriculture has been relatively slow in the USA, with only 0.5% of organic crop and pastureland under organic farms by 2005[14]. The organic industry has experienced periodic shortfalls of some organic products, such as milk and meat, while other domestic products, such as soybeans, have become especially costly at times[15]. The import of organic products in such cases can help organic firms procure needed products and reduce their input costs. However, like consumers, some domestic producers are not welcoming the increased competition from imported organic commodities. In the late 2000s, processors of organic grains, oilseeds and soybeans were concerned about increasing imports of these products[16]. The low organic adoption rate for grain crops, especially, has been a bottleneck for expansion of the US organic livestock sector, with only 0.2% of the US corn and soybean crops grown under the certified organic farming systems in 2005[14].

Data on imported organic products are limited. The extent of international trade of organic products, as well as the impact of increasing trade for both industry stakeholders and consumers, is largely unknown. Recently organic-specific trade codes have been developed to track the flow of organic products both imported and exported from the US. Implemented in 2011, imports of 20 organic products and exports of 23 organic products are being recorded. Over the first 8 months of 2011, the dollar value of the organic products imported was US$509 million, with coffee, soybeans and tea (from the list of 43 products) leading imports[17].

This paper adds to the literature by providing the first examination of imports of organic products into the USA. We use data from a national survey of US certified organic handlers in 2007 to examine the extent, types and origins of imported organic commodities. Unlike the newer trade data that have just now become available, this dataset provides an opportunity to analyze all imported organic products with characteristics and procurement practices undertaken by organic handlers, the primary importers of organic products. As such, we utilize a Heckman model to investigate factors that influence an organic handler's decision to import organic products, and the level at which they import a product. Given these results, we explore future research needs, including studies on consumer preferences and the impact of increased imports on domestic organic farms.

Methodology of Survey of Organic Handlers

A survey of organic handlers was conducted to collect data about their procurement and marketing practices for 2007. The survey instrument was developed in consultation with organic stakeholders, and was administered by Washington State University's Social and Economic Science's Research Center using the Tailored Design Method (TDM)[18]. The survey was authorized by the US Office of Management and Budget (control number 0563-0078). The 58-question survey was developed to study the

basic characteristics of the facilities (sales, function and year first certified organic), marketing practices (products sold, marketing outlet and geographic location of sales), procurement practices (imports, types of procurement arrangements, attributes, and activities with suppliers), and the use of contracts for procurement.

All firms holding certificates to handle organic products were surveyed and approximately 3900 facilities were certified in 2007. The mailing list was created by starting with USDA's National Organic Program list of certified entities, and refining it, using a list of organic handlers developed for a previous (2004) survey to identify facilities under subcontract. All facilities were first pre-notified by postcard. The pre-notification postcard was followed by a letter from the administrators of USDA's Economic Research Service (the lead research organization for the survey) and Risk Management Agency (the funding institution) and letters of support from organic stakeholders, including the Organic Trade Association and the Organic Farming Research Foundation. The survey was sent by first class mail and was followed by multiple carefully timed contacts, including two postcards, a subsequent questionnaire mailing and phone contacts. As an experiment, incentives of US$5.00 were sent with a portion of the surveys. In total, 1408 facilities completed the survey, representing a 39% return rate of eligible facilities. The response rates differed for incentive (50%) and non-incentive (33%) respondents.

To study imports of organic products, the survey gauged the distance over which handlers purchased their ingredients, specifically asking whether, by percentage of volume procured, they procured locally (within an hour's drive), regionally (within state and surrounding states), nationally and internationally. The survey also incorporated additional questions focused on organic imports, including questions on the three primary organic products imported by the facility, the percent of the product's total volume needed that was imported, and the country from which the top product was imported. The products listed by respondents were categorized into 46 individual commodities (such as carrots, corn, apples and pears), and then grouped into nine major product categories (such as vegetables and melons). The vast majority of imported items were reported as individual commodities, with few processed products included on the list. All survey data were analyzed using the statistical analysis program Stata (StataCorp LP, College Station, Texas, USA).

Characteristics of Organic Imports

Summary results from the survey show that a majority of organic products procured by the organic firms came from domestic suppliers, with a little over a third (37%) of handlers importing products. The handlers incurred significant transaction costs in the form of search costs when procuring organic products. In 2007, 52% of all handlers who procured organic products found it difficult to locate needed ingredients, with organic wheat, corn, coffee and soybeans listed as the most difficult to find.

Table 1. Characteristics of the US organic imports, 2007.

Country of imports	Percent of reports	
Canada	13.5	
China	9.5	
Mexico	8.2	
Brazil	6.3	
Indonesia	5.8	
Product categories and commodities imported	**Percent of products reported**	**Average volume imported (%)**
Fruits/tree nuts total	28	56
Miscellaneous fruits and tree nuts (tropical)	10	65
Apples/pears	4	52
Berries	4	39
Oilseeds, grains, legumes and feed total	24	61
Cane products	5	77
Soybeans and soy	3	70
Oil and oilseeds (except soy)	3	70
Greenhouse, seeds mushrooms and herbs total	23	58
Herbs and spices	9	61
Seeds	5	44
Coffee, tea and cocoa total	17	81
Coffee	12	93
Tea	4	56
Cocoa	2	53
Vegetables and melons total	6	54
Tomatoes	2	37
Onions/garlic	1	49

A geographic review of the data reveals that almost half of the organic products imported come from five countries (Table 1). These countries also belong to the top six countries for the importation of all agricultural products in 2011[19]. This relationship between the top countries for importing organic and conventional products suggests that there may be lower transaction costs for organic producers and intermediaries in these countries, as well as a comparative advantage in production systems.

Some of the principal organic products imported in 2007 are those not generally produced in the USA, such as coffee and tropical fruit; for many of these products, most of the volume needed by the handlers is imported (Table 1). The findings also indicate, however, that there are many commodities traditionally grown in the USA that were imported in substantial volume in 2007. Some of these products parallel those imported by conventional handlers, such as off-season fruits and vegetables (e.g., fruit from South America, tomatoes from Mexico and apples from New Zealand). Most notable, however, is the

fact that the category of oilseeds, grains, legumes and feed ranks second in the percentage of imports for 2007, and 61% of the volume of these commodities needed by importing firms came from abroad. Within this product category, the average volume of organic soybeans and oil and oilseeds being imported by firms is quite high (70%), with China being a primary source of these products. Other traditional US crops are on the top imports list, including wheat, barley and berries from Canada (also mirroring conventional imports). Herbs and spices (from Europe, southern Asia and Africa mainly) ranked as the third highest individual commodity imported, with the volume of imports (61% of total volume needed) reported by handlers being relatively high. Organic seeds, from Europe and western Asia, were also imported frequently, although the percent of volume imported was reported to be lower (44%) than other products in the product category.

Modeling a Handler's Decision to Import Organic Products

The analysis of organic handlers, and their decision to import products, is based on the concept that the decision by handlers to import organic products has two parts. In the first part, the firm chooses whether or not to import an organic product; whereas in the second part, the firms decide how much of the organic product to import. This decision framework matches nicely with a sample-selection econometric modeling approach, developed by Heckman[20] and described in detail by Greene[21], that corrects for the bias that occurs in analyzing non-random samples and purchasing decisions. This analysis accounts for both decisions and the fact that they are interdependent, thus avoiding any bias involved if they were considered separately.

Both parts of the organic handler's decision are modeled as follows: We let y_1 be the outcome of the first decision of whether or not to import, and we say that it is related to a latent, unobservable variable y_1'. The observed variable, y_1, takes on a value of 1 if the handler decides to import or 0 if it decides against it. We use y_2 to label the observed outcome from the second part of the handler's decision, the share of the handler's organic product that is imported. Again, we can think of the observed outcome being associated with a latent variable y_2'. We observe y_2 only if $y_1 = 1$, and in that case $y_2 = y_2'$. Modeled more formally, we have the import decision in the first part,

$$y_1 = \begin{cases} 1, & \text{if } y_1' > 0, \\ 0, & \text{if } y_1' \leq 0, \end{cases}$$

and the import share decision in the second part,

$$y_2 = \begin{cases} y_2', & \text{if } y_1' > 0, \\ -, & \text{if } y_1' \leq 0. \end{cases}$$

In other words, y_2 does not take on a meaningful value when $y_1' \leq 0$.

The standard practice is to then specify a linear model with additive errors for the two latent variables:

$$y_{1i}' = X_{1i}'\beta_1 + \varepsilon_{1i} \quad \text{and} \quad y_{2i}' = X_{2i}'\beta_2 + \varepsilon_{2i},$$

where i indexes an individual firm, X_1 and X_2 are covariate vectors that affect the organic importer decision and the import share decisions, and the error terms are correlated and jointly distributed such that $(\varepsilon_1, \varepsilon_2) \sim$ bivariate normal $[0, 0, 1, \sigma_2, \rho]$. Modeled this way, the first decision, then importer decision, affects the outcome of the import share decision. More precisely, the expected value of the import share decision is conditional on not just the β_2 parameters, but also σ_2 and ρ:

$$\varepsilon[y_{2i} | y_{2i} = 1] = X_{2i}'\beta_2 + \rho\sigma_2\lambda(X_{1i}'\beta_1),$$

where $\lambda(X_{1i}'\beta_1)$ is the inverse Mills ratio. To estimate this sample selection model, we employ Heckman's two-step approach. In the first step, we estimate the probit equation for y_1 using maximum likelihood to recover estimates for β_1, and then use these to recover estimates for $\lambda(X_{1i}'\beta_1)$, which can be labeled as $\lambda(X_{1i}'\beta_1)$. In the second step, we recover estimates for β_2 and $\beta_\lambda = \rho\sigma_2$ by a least squares regression of y_2 on X_2 and λ.

Summary statistics for the variables used in this model are given in Table 2. The variables thought to influence whether or not a firm imports organic products (the first stage or selection-dependent variable) include those related to organic sales, with the assumption that smaller firms may be less likely to import organic ingredients than larger firms, which may have greater procurement needs that cannot be satisfied through domestic supply and/or the already established import channels. The extent of the firm's organic sales (versus total sales) is also thought to influence the choice to import, as well as the percent of total procurement that is accounted for by organic; the assumption here is that those with higher organic procurement needs may be more likely to import. In regard to relationships with suppliers, we hypothesize that those facilities prioritizing local suppliers would be less likely to import organic products, while those prioritizing the availability of year-round supply and price would be more likely. We also expected that those facilities working with current suppliers to increase production and/or new suppliers may be more likely to import, as that might signify a high need for organic ingredients. We also assumed that facilities that used a socially responsible label or claim on their products were more likely to import, as many socially responsible claims are Fair Trade labels for products being produced in the developing countries and thus would be imported into the USA. Finally, we expected that those facilities experiencing limited supplies of a major or minor ingredient would be more likely to import organic products.

Those variables thought to affect the decision regarding how much of the organic product to import included size

Table 2. Summary statistics of variables used in model.

Variable	Definition	All handlers, mean (SD)	Importing handlers, mean (SD)
Small organic	1 if less than US$500,000 in organic sales, else 0	0.51 (0.50)	0.45 (0.50)
Very large organic	1 if more than US$5 million in organic sales, else 0	0.13 (0.33)	0.18 (0.39)
All organic	1 if all facility sales were organic (no conventional product sales), else 0	0.18 (0.38)	0.18 (0.39)
> 50% organic	1 if organic sales were 50% of more of all gross sales, else 0	0.37 (0.48)	0.43 (0.50)
Limited ingredients	1 if the facility found organic products or (major or minor) ingredients to be in limited supply at any point in 2007, else 0.	0.52 (0.50)	0.58 (0.49)
Local priority	1 if the facility places a high priority on local suppliers in choosing certified organic supplies, else 0	0.36 (0.48)	0.27 (0.44)
Price priority	1 if the facility places a high priority on price in choosing certified organic supplies, else 0	0.45 (0.50)	0.27 (0.50)
Year-round priority	1 if the facility places a high priority on the availability of year-round supply in choosing certified organic supplies, else 0	0.52 (0.50)	0.56 (0.50)
Social label	1 if uses a socially responsible label or claim on organic products produced, else 0	0.10 (0.30)	0.18 (0.38)
Works supply	1 if the facility is working with new organic suppliers (less than a year in business) or is working with current suppliers to increase production, else 0	0.41 (0.49)	0.48 (0.50)
Organic procurement	Percentage of the facility's 2007 procurement (by volume) that was organic	42.34 (40.94)	45.99 (40.42)
Coffee, tea and cocoa[1]	1 if the most important organic product (by volume) is coffee, tea, or cocoa, else 0	NA	0.23 (0.42)
Berries[1]	1 if the most important organic product (by volume) is berries, else 0	NA	0.03 (0.16)
Tropical fruits[1]	1 if the most important organic product (by volume) is tropical fruits, else 0	NA	0.08 (0.28)
Soybeans[1]	1 if the most important organic product (by volume) is soybeans, else 0	NA	0.05 (0.21)
Grain feed oil[1]	1 if the most important organic product (by volume) is corn, oat, oilseeds, barley or wheat, else 0	NA	0.09 (0.28)

N for all organic handlers = 1049; *N* for importing organic handlers = 442.
[1] Only those handlers importing a product can be used to calculate a mean and standard deviation.

of organic sales and the amount of a facility's gross sales accounted for by all organic sales. In addition, we assumed that those firms experiencing limited supplies of a needed ingredient would affect the share of product imported. Finally, numerous product variables were included to study whether organic products that are either not produced in the USA (such as coffee and some tropical fruits), have been in limited supply (grains and soybeans) in the past, or are imported at high rates from other countries in the conventional sector (berries) affect the share of that product being imported, in this case positively.

The results of the model are given in Table 3. It should be noted that an alternative to the two-step approach is to estimate both of the modeled decisions simultaneously using maximum likelihood methods. The authors checked results from this method against the two-step approach and found that the parameter estimates for beta1 and beta2 are extremely close. Results from the first step indicate that the size of a facility's organic sales is important in deciding whether a handler imports or not, with smaller facilities less likely to import an organic product, while larger facilities are more likely to import. Facilities with 50% or more of all gross sales accounted for by organic products were also more likely to import, while the variable that represented firms where 100% of sales were organic was not statistically significant. Facilities prioritizing suppliers that are local, not surprisingly, were less likely to import organic products, while prioritizing year-round supplies and prices when choosing a supplier did not make a difference. Facilities using a social label or claim on their organic products were also more likely to import organic products, which is not unexpected since many organic coffee and cocoa products carry Fair Trade labels and these products are high on the list of imported organic products. Finally, those facilities actively working with suppliers to increase organic ingredient supplies or working with new suppliers (less than a year in business) were also more likely to be importing organic products, possibly an indication that they are unable to procure enough supply domestically. Also not significant in the model were the percentage of overall procurement accounted for by organic products, as well as facilities that experienced limited supplies of organic ingredients in 2007.

In the second stage, the variable representing size of the facility indicated that higher organic sales were not significant, while the share of organic product imported

Table 3. Results of the model for importation of organic products.

Variable	Stage one: importing handler	Stage two: share of product from imports
Small organic	−0.229**	0.137*
Large organic	0.410*	−0.047
All organic	−0.150	−0.117**
>50% organic	0.462*	−0.013
Limited ingredients	0.126	0.019
Local priority	−0.483*	Excluded
Price priority	−0.097	Excluded
Year round priority	0.143	Excluded
Social label	1.301*	Excluded
Works supply	0.257*	Excluded
Organic procurement	−0.002	Excluded
Coffee, tea and cocoa	Not applicable	0.164*
Berries	Not applicable	−0.343*
Tropical fruits	Not applicable	0.141
Soybeans	Not applicable	0.071
Grain feed oil	Not applicable	−0.056
Inverse mills (λ)		−0.133**

* Denotes significance at the 5% level.
** Denotes significance at the 10% level.
Number of observations: 565; censored observations: 350; uncensored observations: 215; log likelihood = −326.004.

increased for facilities with lower organic sales. So, although facilities with lower organic sales were less likely to import, once that decision was made, the share they imported was higher. In the first step, while we saw that those with 50% or more of all sales accounted for by organic products were important in the decision to import, this variable was not significant for the share imported, and in fact, the share of the imported product decreased in facilities where all sales were accounted for by organic. Included in the second step were commodity variables for products imported. The share of organic product imported increased for those facilities importing coffee, tea or cocoa, suggesting that these products are primarily obtained through imports, while it decreased for berries, suggesting that imports of berries may make up for seasonal fluctuations or limited supplies. Variables for other commodities—including tropical fruits, which are generally grown outside the USA, soybeans, grain, feed and oilseeds—were surprisingly not significant.

Discussion of Results and Next Steps

Anecdotal evidence suggests that the import of organic products in the USA has grown over the past decade. US consumers and producers have, at times, raised concerns over the increase of imports and the potential loss of markets to non-domestic sources. For some consumers, the act of importing organic food conflicts with what they consider the intentions of organic production and consumption. However, assessing the veracity of these concerns is made difficult by the lack of data, prohibiting research on trade flows of organic products, and farm-level impact.

Organic handlers, the primary importers of organic products into the USA, have various reasons for choosing to import products. The summary results show that many of the products being imported into the USA are products that cannot be produced domestically, including coffee and tropical fruits. On the other hand, some oft-imported commodities are those that can be produced in the USA, such as soybeans, oil/oilseeds, wheat, barley, berries, and herbs and seeds. Conventional versions of some of these products, specifically wheat and berries, are often imported in the USA from Canada. Some other conventional versions of these organic products, such as soybeans, are not traditionally imported. When examined in the light of slow growth in US certified organic acreage in grains and soybeans, these findings suggest that supply shortages may be the motivation for importing these specific products. However, using the Heckman model, we found that importing coffee, tea or cocoa was the only commodity category that influenced the share of product imported positively. Importing berries, on the other hand, influenced the share of product imported negatively. Social labels, such as Fair Trade, positively affected a handler's decision to import; not surprising in that Fair Trade products, by definition, are usually grown outside of the USA.

The summary results also show that organic handlers are procuring almost a half of their imported products from a few countries, including Canada, China, Mexico, Brazil and Indonesia. In the analysis, we did find that those handlers prioritizing local suppliers, not surprisingly, negatively affected the facility's decision to import products. This could be associated with consumer demand for local products. Although consumers seem to be concerned by imports of organic products from China, at least as described by the popular press and by surveyed organic food retailers[8], consumer response to imports from other countries seems to be fairly muted. Some recent (yet limited) research does provide some insight into US consumers' view toward organic soymilk, with consumers strongly preferring soymilk ingredients produced in the USA and Canada over soymilk ingredients produced in Brazil, China or India[22]. As noted below, additional consumer research examining preferences for organic foods is needed.

Handlers may also be experiencing limited supplies and high-input costs, and using imports to shore up supply needs or reduce input costs. Our analysis of the data uncovered that although many handlers are experiencing limited supply of inputs, this did not impact a handler's decision to import products. This suggests other reasons for importing, such as input prices, but again, price was

not found to be significant in the model. In terms of supply, handlers working with suppliers to increase supply were more likely to import. This could indicate an inability to procure supply domestically, but it could also mean that they are also working to increase supply outside of the USA.

Lastly, and perhaps most significant, size of organic sales was important to both the decision to import and the share imported, with larger firms more likely to import and smaller firms less likely to import. However, once a smaller firm had decided to import, they imported a larger share of their needed inputs. This suggests that the supply chain structure might be an important factor—so that larger firms, which may be more likely to have international supply chains already established, are more likely to import products. But, smaller firms, once they make the decision to import and establish the supply chain, are likely to focus on those supply chains to procure their product.

Given the lack of supply-side policies and support payments for organic production in the USA, and historically slow adoption rates for certified acreage over the past decade, consumer demand for organic products in the USA is likely to continue to increase more rapidly than organic farmland. At the same time, international aid for organic agriculture is growing in developing countries, translating into rapidly increasing organic acreage in these countries. The recent equivalency agreement with Canada, the US's largest agricultural trading partner, will likely greatly impact US trade of organic products. The new equivalency agreement with the EU will also likely expand the trade of organic products further between the two countries. Taken together, these factors suggest that organic imports into the USA will continue at current levels or increase in the future. However, in the absence of analytical research on the international trade of organic products, it is not clear how the policies facilitating international trade of organic products will affect consumer welfare in the USA. The key question at the core of this debate is whether a country (the USA or other countries)—including its consumers and farmers—benefits from increased international trade of organic products. The answer is not straightforward because we do not understand the distribution of consumer preferences for imported organic products, and thus cannot make inferences about the welfare effects of importing organic products.

Thus, when considering a research agenda for the international trade of organic products, one critical research stream needs to address consumer preferences for imported organic products. For example, are consumers generally accepting products that cannot be grown domestically, such as coffee, off-season produce and tropical products? What about products that can be grown domestically, such as wheat, which are generally imported in their conventional versions? Does this differ from products, such as soybeans, that are traditionally produced domestically, but organic versions are being imported? Another issue is whether the US consumers take into account the political or cultural reasons for their choices; for example, are they more accepting of standards from developed countries (such as the EU and Canada) than they would be of those from developing countries (such as China or Latin American countries)? Does distance from the exporting country matter? Finally, do food scares in the conventional sector (such as those in China over the past several years) have an impact on organic imports from those countries?

A good starting place would be a consumer study, most likely requiring an experiment or a stated preference study, so that these specific questions could be addressed. A comprehensive consumer study capturing all aspects of the way people shop for food, in particular, the spatial dimensions that affect food purchasing decisions (e.g., through substitution possibilities between organic and conventional products, as well as among different organic products available) would also be of benefit to understanding consumer preferences and imported food products. For example, consumers may examine several products during each individual shopping trip before making their purchase decision, comparing not only relative prices, but perceived quality and other characteristics such as product origin.

Of course, understanding the impact of imported organic products for the US farms and intermediaries is also important. For example, increased availability of organic products may increase consumer awareness of organically produced food, which may have a positive effect on the farm sector through increased market demand. Thus, greater availability of organic berries and soy products may be beneficial for the US farmers by increasing the market for organic products overall. However, if imported organic products are less costly than domestically produced organic commodities, especially those in short supply at the farm level, unless US farmers can reduce costs to compete on price, imports may have a negative effect on the domestic farm sector. On the other hand, if consumers demand domestic organic products over imported products, how will this affect the farm sector and market?

The questions are likely less complicated for intermediaries. Sitting between the farm and the consumer, these firms will most often select ingredients and products that will yield the highest profits. The prices they can charge depend partly on consumer preferences, so if consumers are willing to pay more for domestically produced products (and if higher profits follow), intermediaries will respond by using such products. If consumers are indifferent to the origin of the organic products they purchase, these firms will generally choose the lowest cost products; in this case, the relative costs will depend on the usual factors such as domestic supply, international supply and transportation costs. Thus, the juxtaposition of the consumer and the farmer will largely

determine how the intermediaries respond, and will have an impact on the dynamics of the supply chain and ultimately on aggregate consumer and producer welfare.

Addressing these research questions and needs would greatly enhance our understanding of the organic market and the impacts and dynamics surrounding the import of organic products and ingredients. In addition, the new data from the US government tracking exports and imports of organic products, although limited in the number of commodities tracked, may also shed light on the market and supply chain dynamics in the organic industry. Researchers interested in organic in other countries likely face questions of their own about the impact of organic trade. Multi-country studies that examine consumer and producer impacts of organic trade would provide a foundation for unraveling the differences and similarities that likely exist.

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Reversion from organic to conventional agriculture: A review

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Abstract

Over the past 10 years, the organic sector has expanded continuously in Europe due to policy support and a growing market demand for organic products. In line with this development, many farmers converted to organic farming each year. Nevertheless, the total number of organic farms has not increased constantly in Europe. In several countries, the absolute number of organic farms actually decreased in some years of the past decade. Some of the deregistered farmers gave up completely; others reverted to conventional agriculture. Against this background, this article aims (i) to give an overview of the extent of reversion to conventional agriculture in Europe based on statistics, (ii) to conceptualize the decision to revert in the form of a theoretical model, (iii) to compare farmers' reasons to revert to conventional farming based on existing studies, and (iv) to identify further research needs. The importance of reversions to conventional agriculture is difficult to determine with the existing data, especially as in most cases it is not recorded as to what happened to the farms after deregistering from organic certification. The data nevertheless show that there are large fluctuations in the organic sector with many farmers entering and exiting each year. In order to reveal the farmers' reasons for deregistering, various qualitative as well as quantitative surveys have been carried out already. For most farmers, the decision to revert is a result of different factors. Reasons for the reversion of their farms can be classified into economic motives, difficulties regarding certification and control, problems with organic production techniques as well as the farms' macro environment. In most cases, however, economic reasons played a main role. Suggestions for organic legislation bodies, advisory services and policy makers are derived out of the findings. A deeper understanding of the influencing aspects regarding reversions and the necessary changes in the organic sector to avoid them should be an important objective of forthcoming research.

Key words: reversion, conversion, dropping out, organic agriculture

Introduction

Over the past 10 years, the organic sector has expanded continuously in Europe due to policy support and a growing market demand for organic products[1]. Many farmers convert to organic farming each year, in line with this development. Nevertheless, the total number of organic farms has not increased constantly in Europe. In several countries, the number of organic farms decreased in some years of the past decade. This holds true for Austria (1999–2001, 2006, 2007), Denmark (2003–2006, 2008, 2009), Finland (2001, 2003–2006, 2008), Netherlands (2003–2006), Switzerland (2006–2009) and the United Kingdom (2003, 2005, 2008, 2009)[2].

However, these data provide no information about how many organic farmers gave up completely and how many farmers reverted to conventional agriculture (in this article, the term reversion stands for farms which were once certified organic but deregistered from organic certification and control in order to continue farming conventionally). Besides, the figures representing the total number of organic producers per year include dropouts and newcomers simultaneously. Therefore, high fluctuations caused by a large number of farmers

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Table 1 Share of deregistered producers and net change from 2000 to 2010 in European countries.

	Share of deregistered producers as percentage of organic producers per country and year											Net change between 2000 and 2010	
Country	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Number of farms**	**%**
Greece	**25.2**	n.d.	**60.0**	**10.9**	**12.4**	9.4	9.4	9.9	4.0	8.1	**17.2**	+15,931	+298.2
Spain	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.5	n.d.	7.3	7.9	n.d.	+14,483	+108.1
France	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.3	+11,619	+129.3
Germany	3.1	3.8	5.0	5.8	7.0	5.0	3.9	3.5	3.5	3.3	4.2	+9,202	+72.2
Austria	5.4	n.d.	n.d.	n.d.	1.8	1.5	n.d.	n.d.	n.d.	n.d.	n.d.	+1,973*	+10.4*
Sweden	9.3	4.1	**11.1**	7.9	6.6	**19.1**	4.8	n.d.	n.d.	n.d.	5.4	+1,582	+43.6
UK	n.d.	n.d.	n.d.	n.d.	n.d.	**10.8**	**14.1**	7.2	**15.0**	9.1	8.7	+1,386	+38.9
Norway	6.5	6.5	8.6	8.5	7.9	6.1	6.3	6.1	6.9	5.7	6.8	+965	+52.4
Switzerland	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	+757	+15.4
Ireland	n.d.	n.d.	n.d.	n.d.	5.6	2.3	3.8	1.8	3.6	6.5	n.d.	+476*	+55.9*
Belgium	7.1	**10.5**	**11.2**	**15.4**	8.2	2.6	6.7	6.3	8.7	6.5	n.d.	+373*	+59.8*
Netherlands	n.d.	n.d.	n.d.	n.d.	8.5	4.1	2.2	n.d.	n.d.	5.3	2.9	+333	+29.5
Luxembourg	6.5	2.0	1.9	3.4	0.0	6.8	n.d.	n.d.	n.d.	n.d.	n.d.	+46*	+148.4*
Denmark	2.4	6.2	1.4	7.6	**13.6**	7.9	**12.3**	n.d.	7.1	6.2	4.5	−789	−22.8
Finland	7.2	8.4	2.9	5.5	n.d.	**13.9**	**11.6**	4.3	4.6	2.7	5.0	−1,203	−23.0
Italy	3.9	8.4	9.9	**28.9**	**34.4**	7.7	7.9	7.9	**11.2**	**14.4**	**19.1**	−10,989	−20.8
Bulgaria	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.0	**18.8**	**39.0**	4.3	4.1	n.d.	n.d.
Czech Rep.	n.d.	n.d.	n.d.	n.d.	1.3	6.6	3.6	3.0	3.4	5.1	5.2	n.d.	n.d.
Estonia	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2.9	4.8	3.6	**12.1**	6.1	n.d.	n.d.
Latvia	n.d.	n.d.	n.d.	n.d.	4.4	0.4	1.1	1.2	1.9	5.8	**17.9**	n.d.	n.d.
Lithuania	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	**10.9**	n.d.	n.d.	n.d.
Hungary	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	13.3	n.d.	n.d.
Malta	n.d.	n.d.	n.d.	n.d.	0.0	0.0	0.0	n.d.	n.d.	**29.4**	**18.2**	n.d.	n.d.
Portugal	8.9	6.6	8.6	0.0	0.0	0.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Slovenia	n.d.	n.d.	n.d.	n.d.	3.4	**12.5**	3.2	n.d.	2.5	6.9	5.5	n.d.	n.d.
Slovakia	n.d.	n.d.	n.d.	**11.4**	**11.1**	**15.9**	8.7	3.9	9.2	**11.0**	n.d.	n.d.	n.d.
Cyprus	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Poland	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Romania	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d. = no data.
* = net change calculated between 2000 and 2009 as data for 2010 were not yet available.
Source: Own compilation following[2].

leaving organic certification while at the same time many others newly registering for it are not necessarily conspicuous as long as the overall number is still increasing.

Against this background, this article aims (i) to give an overview of the extent of reversion to conventional agriculture in Europe based on statistics, (ii) to conceptualize the decision to revert in the form of a theoretical model, (iii) to compare farmers' reasons to revert to conventional farming based on existing studies, and (iv) to identify further research needs.

In the following sections first an overview of the extent of reversion in Europe and the USA is given based on official statistics as well as on results of studies. Subsequently, the theoretical model is described, which is applied in order to understand the reversion decision. This is followed by a review of the research results about the reasons for reversion. Finally, some conclusions for further research are drawn.

Dimensions of Reversion

Official statistics on reversion

The statistical data are supplied by the European statistical database Eurostat, which gives an overview about the entrants and dropouts in organic farming. For some countries, however, only the total number of organic farms per year is available without the respective share of newly converted farms and the number of those who reverted. For some other countries, the data are completely missing. In addition, it has to be noted that the statistics regarding deregistration only give a total figure of all the deregistered farms and do not differentiate between the reversions to conventional agriculture and farmers giving up farming altogether. Due to the amount of missing data, it is difficult to report the overall trends across countries over time. Nevertheless, some interesting developments can be observed as shown in Table 1.

Table 2 Deregistered farms and total number of farms.

Country	Deregistered farms	Measured period	Total number of organic farms (year)
Austria[7]	3419 deregistered	2000–2002	20316 (1998)
Denmark[8]	266 deregistered	2003	3500 (2003)
Ireland[9]	>200 deregistered	2003–2006	n.d.
Norway[10]	523 deregistered	2004–2007	1913 (2006)
Switzerland[11]	281 reverted +233 stopped farming	2005–2007	6349 (2005)
United Kingdom[12]	204 deregistered from Soil Association	1993–1999	n.d.
USA (California)[13]	1334 deregistered	1992–1996	1469 (1996)
USA (California)[14]	358 deregistered	2002	1847 (2002)

n.d. = no data.
Source: own compilation.

In Greece, there were several years with an extremely high percentage of reversions, especially 2002, where 60% of all organic farmers reverted. Not surprisingly, the total number of Greek organic farms actually decreased in 2002, as well as in 2007, 2008 and 2010. Looking at the whole period between 2000 and 2010, however, reversions were more than compensated for by a large number of new conversions to organic farming. The overall number of organic farms in Greece has therefore increased by almost 16,000 farms during this time, which represents a growth of nearly 300%. A large net increase of over 10,000 organic farms, which represents a growth of more than 100% between 2000 and 2010, also happened in Spain and France. For these countries, however, there are hardly any data available regarding reversions or new conversions in the intermediate years.

Germany and Norway had steady dropout rates, always remaining under 10% of all organic farms per year. Over the 10-year period, both countries had a net increase in the number of organic farms, which lay above 50% in Norway and above 70% in Germany. In Belgium, dropout rates varied considerably between 15% in 2003 and 3% in 2005. Nevertheless, the overall number of organic farms increased over the period between 2000 and 2009 by almost 60%.

In Denmark, Finland and Italy the total number of organic farms decreased since 2000. The largest net decrease happened in Italy with almost 11,000 fewer organic farms in 2010 than in 2000, which represents a decrease of about 20%. In Italy, the largest deregistration rates appeared in 2003 and 2004. Similarly decreases of more than 20% over the 10-year period can be observed in Finland and Denmark, although the overall number of organic farms is much lower in these countries.

Evidence of reversion from the literature

The dimensions of reversion in the respective countries were determined in the examined studies either by asking current organic farmers about their intentions regarding the prolongation of organic farming, by surveying ex-organic farmers or by analyzing national statistical data about deregistered producers.

When asked about their intentions concerning the continuance of organic farming or planned reversion to conventional agriculture, there were very similar results in different European countries and in different years. In an early study in Germany in the 1990s, 14% of the interviewed organic farmers were determined to revert after the expiration of the first organic program, whereas 36% were undecided[3]. Ten years later in a Danish study, 13% considered reversion within the following 5 years[4].

An interesting course of studies was conducted in Austria: In a survey in 1999, 13% of the interviewed organic farmers were determined to revert and 23% were undecided[5]. Of those farmers who participated in the follow-up survey 3 years later, 13% had actually reverted. The reverted farmers were mostly those who had indicated earlier that they planned to revert, but also some who had originally been undecided or intended to stay organic[6].

More accurate indicators of reversion are therefore figures of farms which already reverted to conventional agriculture. The reviewed literature[7–14] gives various figures regarding the number of deregistered farms in the respective countries (see Table 2). However, in most cases the statistics only describe the deregistered producers in general and do not differentiate between the reverted farmers, namely those who once farmed organically and are now farming conventionally, and those farmers who once farmed organically and gave up farming completely. The termination of the whole farming enterprise is a general problem of agriculture in the context of overall structural change, which is not the focus of this article. A comparison between different countries is furthermore difficult due to a very heterogeneous reference framework, as some authors report deregistered producers per country and year, others over a period of several years or only those deregistered from one certification body.

Table 3 Motivations to convert to organic production.

Farming related motives	Personal motives
Husbandry and technical reasons	**Personal health**
• Animal health problems	• Own and family health problems
• Soil fertility and erosion problems	• Ergonomic reasons
Financial motives	**General concerns**
• Solve existing financial problems	• Food quality
• Secure future of the farm	• Nature conservation and environment
• Cost saving	• Rural development
• Premium marketing	

Source: [16].

Framework

In order to conceptualize the decision to revert a farm, a theoretical model based on decision theory is developed. Decisions can be understood as a choice between different options, which aim to achieve certain goals. According to Mintzberg et al.[15], the process of decision-making consists of the following activities which are not necessarily made in a sequential order: (i) identification of problems and opportunities, (ii) definition and clarification of options, and (iii) evaluation and choice between alternatives. Putting this into the context of reversion, the decision to return to conventional farming is the choice of an alternative to organic farming. It is therefore a correction of a previous decision (to convert the farm) based on an ex-post evaluation of the conversion decision and an ex-ante evaluation of maintaining the organic status. (This refers to the situation in which a farmer first converts and later reverts the farm. Cases in which a reversion is due to new farm management are not taken into account.) A reversion occurs if the ex-post/ex-ante evaluation leads to a negative judgment of the organic status and/or if the net utility of conventional management is expected to be higher in the future. Following these thoughts, reasons for the decision to revert can be divided into (i) unmet expectations, (ii) promising alternatives, and (iii) the judgment of transaction costs.

Key elements of post-evaluation are expectations connected to the conversion. From the literature it is known that farmers convert to organic farming for various reasons. Padel[16], for example, divides the reasons for conversion to organic farming into farming related and personal motives (Table 3). The farming related motives consist of animal husbandry, technical reasons and/or financial motives. Personal health and general concerns such as the state of the environment or food quality are personal motives for conversion.

The relative importance of the different motives varies. In a Canadian study it was found that 'health and safety concern and environmental issues are the predominant motives for conversion, while economic motives are of lesser importance'[17]. Several other studies also emphasize that social[18], health, or environmental reasons[17,19,20] play a significant role. Nevertheless, in other studies it was found that subsidies[21–24] and supposedly higher profits[21,25] are the driving factors for converting to organic farming. Since conversion-related motives are connected to specific expectations, reversion to conventional farming methods can be explained by unmet expectations and a perceived lower utility of the organic system than expected. In this context, utility can be defined as the sum of economic benefits and the value to act according to one's personal beliefs[26]. In algebraic terms, the relationship between expected and effective utility of organic farming can be formulated as follows, with $E(U_{org})_{t_0}$ as expected utility before the conversion and $(U_{org})_{t_1}$ as effective utility after the conversion:

$$E(U_{org})_{t_0} > (U_{org})_{t_1}$$

A simple example is the expected profit under organic management. If the farmers are not able to obtain premium prices and yields decrease substantially, the profits can be lower under organic management than initially expected. In this case, the expectation that a conversion to organic farming would solve financial problems is not fulfilled.

Unmet expectations do, however, not necessarily lead to reversion. For this, it is also relevant that the conventional system represents a realistic alternative. It is important to bear in mind that the net utility of either organic or conventional farming is not static over time. Changing framework conditions can decrease the utility of the organic system (e.g. due to new organic regulations which are difficult to implement) and/or increase the utility of conventional management (e.g. due to rising conventional prices). Another element of the decision to revert is therefore based on an ex-ante evaluation of alternative (non-organic) management strategies and the expectation that they will lead to a higher utility. A reversion becomes likely if the expected utility of future conventional farming $E(U_{con})_{t_2}$ is higher than the expected utility of maintaining the organic status in the future $E(U_{con})_{t_2}$. In algebraic terms, this can be formulated as

$$E(U_{con})_{t_2} > E(U_{org})_{t_2}$$

A third element is related to transaction costs. Reversion to conventional farming could, for example, mean that specific machinery used for organic management techniques has no or only little use under conventional management. In fact, all conversion-related investments can be counted as transaction costs. Besides, if an organic farm receives organic support payments under agri-environmental programs of the EU, a reversion before the end of the 5-year contract period implies that the farmer has to reimburse the payments received under the current

management contract. High transaction costs are therefore an important barrier for reversion in EU countries.

Thus, the utility of reversion U_{rev} can be divided into three elements: (i) the difference between expected and effective utility of the organic system with respect to economic performance, animal husbandry and technical problems, personal health, nature conservation and environment, food quality and other aspects; (ii) the difference between the expected utility of conventional and organic farming in the future; and (iii) the transaction costs of reversion TC_{rev}.

$$U_{rev} = E(U_{org})_{t_0} - (U_{org})_{t_1} + E(U_{con})_{t_2} - E(U_{org})_{t_2} - TC_{rev}.$$

From a theoretical point of view, a reversion would be useful for a farmer if the utility U_{rev} has a positive value.

Empirical Evidence on Farmers' Reasons for Reversion

Approach

In order to reveal farmers' reasons for reverting to conventional farming methods, a thorough literature research was conducted in scientific journals, databases, library catalogues, gray literature, project reports and online publications. In total, 12 relevant studies were identified from six EU-countries (Austria, Denmark, Estonia, Ireland, Italy and the United Kingdom) and two non-EU-countries (Norway and Switzerland). Additionally, three studies dealing with reversion of organic farms in the USA were found. Since the organic certification and support policies in the USA differ substantially from the situation in Europe, the reasons for reversion in the USA are discussed here only marginally. An overview of the studies is given in Table 4[3–14, 27–49].

Reasons for reverting from organic to conventional farming

Researchers facing the phenomenon of reversion used different approaches by surveying farmers and consultants or analyzing organic registration data. The most commonly used survey method to identify reasons for reversion was a written or telephone survey with all or a sample of farmers who deregistered during a certain period, asking about their reasons in retrospect, e.g. in Austria[7,29–31], Estonia[34], the United Kingdom[12,46] and the USA[14]. In Ireland[9] and Norway[10,36,40,41], researchers surveyed organic and deregistered farmers simultaneously, in Switzerland additionally conventional farmers[11,42–45]. Kirner et al. (Austria[6,28]), Kaltoft and Risgaard (Denmark[8]), Koesling et al. (Norway[37,38]), Harris et al. (United Kingdom[47]) and Sierra et al. (USA[14,49]) used a qualitative survey with farmers and/or agricultural consultants to accompany quantitative results. In Germany[3], Austria[5,27] and Norway[10], organic farmers were asked whether they intended to continue organic farming during the next 5–10 years or after the current organic program ended. In Austria[6,28], this study was complemented by a follow-up survey to determine the actual farming status some years later. Harris et al. (United Kingdom[47]) and Klonsky and Smith (USA[13]) on the other hand analyzed registration records in order to find determinants for reversion in the structural data of farms. Koesling and Løes[50] already presented a comparison of reasons for reversion in Austria, Denmark, Estonia, and Norway.

Analyzing the literature, the farmers' reasons for the reversion of their farms can be roughly classified into economic motives, difficulties regarding certification and control, and problems with production techniques and the macro environment of the organic farm (see Table 4). For most farmers, however, the decision to revert is a result of different factors, including various additional individual or personal ones.

Economic reasons. Nearly all studies point out that economic problems are the main reason for most organic farmers to revert. Agricultural consultants in Denmark explained that only a few organic farmers would consider reversion at all if the overall economic basis was better[8]. Harris et al. (United Kingdom[47]) and Läpple (Ireland[9]) also found that some farmers apparently reverted only due to economic necessities.

According to Schneeberger et al.[27], the difference between organic subsidies and payments through other environmental programs in Austria was too small. Ferjani et al.[44] also reported that organic subsidies and direct payments were too low and uncertain in Switzerland. In a German study, Hamm et al.[3] found that one-third of the surveyed 118 farmers had converted mainly due to attractive organic subsidies in a certain extensification program. Consequentially, when asked about the continuance of organic agriculture under another program with reduced subsidies, only 50% were determined to continue, whereas the other half was either undecided or determined to resign from certification. In Denmark, some farmers stated that they only converted to organic in order to use organic subsidies for the further development of their farms (e.g., build new stables). They had never planned to continue with organic farming beyond the first 5-year period[8].

Several authors suggested that producer prices for organic products were generally not sufficient to compensate increased production costs (e.g. in Austria[6,7], Switzerland[45] and Norway[10,37]). When asked in detail, farmers complained about insignificant organic price premiums compared to conventional products, whereas the additional time and effort as well as prices for purchased fodder or seeds were too high (Austria[7,27]). They also mentioned difficulties to obtain organic fodder and seeds. Ploomi et al. (Estonia[34]) reported that some farmers reverted because they experienced a higher workload for organic methods and simply did not have enough workforce.

Table 4 Studies about deregistered organic farmers.

Country	Year of survey	Data collection method and sampling	Analyzed sample regarding reasons for reversion	Analysis methods	Reasons for reversion
Austria I[5,6,27,28]	1999, 2002, and 2004	(a) Out of a total of 18,960 organic farmers in Austria, random selection of 1500 for a written survey in 1999 (600 responses). Selection of farmers intending to commit to a further 5-year period of organic farming once the first program ended (388 continue organic, 76 end participation, and 136 undecided). Out of those intending to end participation and those undecided, 48 gave contact details (b) Written survey with those 48 farmers in 2002 (38 responses). Out of these, 13 actually reverted (c) Telephone interviews in 2004 with these 13 farmers and with five farmers who had intended reversion but continued organic farming	(a) 600 farmers (587 indicated year of conversion)→212 farmers intending reversion or undecided (b) 38 farmers intending reversion or undecided (c) 13 reverted farmers and five organic farmers	Descriptive analyses Factor analysis	• Low price difference between organic and conventional products • Bureaucracy • High production costs • Changes in standards • Low difference in subsidies compared with other programs • Frequent and strict controls • Animal feeding (limitations and costs)
Austria II[29,30]	2000	Written survey with all 745 reverted farmers in Tirol (334 responses) Further analyses of Austria I with regard to Tirol (83 farmers in Tirol)	334 reverted farmers	Descriptive analyses	• Low subsidies • Low price difference between organic and conventional products • Marketing problems • Strict controls • Dislike of control
Austria III[7,31]	2003	Out of a total of 3419 farmers who deregistered between 1999 and 2002, random selection of 1200 for a written survey in 2003 (472 responses)	326 reverted farmers	Descriptive analyses Factor analysis	• High prices for fodder • Low price difference between organic and conventional products • Changes in standards • Dislike of control • Bureaucracy • Lacking infrastructure for marketing
Denmark[4,8,32,33]	2002 and 2003	(a) Interviews with ca. 10% of all organic farmers in 11 study areas in Denmark (b) Two qualitative studies containing personal interviews with agricultural consultants and farmers who reverted or considered reversion (identified in (a))	(a) 347 organic farmers (b) Both qualitative studies together: eight consultants, 11 farmers (reverted or considering reversion)	Descriptive analyses Qualitative analyses	• Financial reasons • Marketing problems • Letting of land is more profitable • Land scarcity • 5-year commitment • Changes in standards • Bureaucracy • Weeds

Estonia[34]	2005	Telephone interviews with 92 farmers who reverted	64 reverted farmers	Descriptive analyses	• Financial reasons • Bureaucracy • Weeds and phytosanitary problems • Regulations regarding animal husbandry • Marketing problems
Germany[3]	1996	Written survey with all 445 organic farmers in Mecklenburg-Western Pomerania (137 responses)	118 organic farmers	Descriptive analyses	• Lowered subsidies
Ireland[9]	2008	(a) Written survey with all organic and reverted farmers in 2008 (b) Data on conventional farmers collected through 'Teagasc National Farm Survey' Restriction of analysis to drystock farms	(a) 341 organic farmers, 41 reverted farmers (b) 164 conventional farmers	Factor analysis Duration analysis (period 1981–2008)	• Higher probability to revert if farmer has off-farm job • Higher probability to revert after 5 years than before
Italy[35]	1993–2006	Analysis of the database of a certification body (IMC) in the Marche Region	966 organic farmers	Bayesian Network	• Influencing factors on reversion are age, province, and farm size
Norway[10,36,41]	2007	(a) Analysis of structural data (b) Personal interviews with reverted farmers and agricultural consultants (c) Written survey in 2007 with all 523 farmers who had deregistered between 2004 and 2007 and with (d) 621 organic farmers (random sample of all 1913 organic farmers) → Question on expected farming status in 5–10 years	(a) Seven farmers, five consultants (b) 220 deregistered farmers (170 reverted, 36 stopped farming, 14 mistakenly deregistered or converted again), 407 still organic farmers (c) 277 farmers intending to revert or to stop farming	Qualitative analyses Descriptive analyses Factor analysis	• Changes in standards • Bureaucracy • Low subsidies • Low organic price premiums • Animal husbandry

Table 4 (*Cont.*)

Country	Year of survey	Data collection method and sampling	Analyzed sample regarding reasons for reversion	Analysis methods	Reasons for reversion
Switzerland[11,42–45]	2009	(a) Analysis of structural data of organic farmers from the 'Bundesamt für Landwirtschaft' (AGIS) (b) Written survey with 3425 farmers (991 long time organic farmers (at least since 2005), 281 farmers that deregistered 2006/07, 153 new converters in 2006/07, 2000 long time conventional farmers) (c) Written survey with ca. 400 agricultural students	(a) 1177 farmers (580 conventional farmers, 450 long time organic farmers, 60 new organic farmers, 87 deregistered farmers). (b) 256 agricultural students	Descriptive analyses Factor analysis Logistic regression	• Changes in standards • Strict standards • Low organic price premiums • High production costs • High prices for fodder • Low subsidies • Control costs • Access to organic litter and fodder
UK I[12,46]	1996 and 2000(?)	(a) Dataset collected in 1996 from 86 organic farmers (b) Telephone interviews (and some written questionnaires) in 2000(?) with all 204 farmers who deregistered from 'Soil Association' since 1993	(a) 86 organic farmers (b) 35 deregistered farmers	Qualitative and quantitative analyses Logit model	• Marketing problems • Financial reasons • Production problems
UK II[47]	2004	(a) Data about the number of farmers who deregistered between 2000 and 2003 from the two largest certification bodies in the United Kingdom ('Soil Association' and 'Organic Farmers and Growers') who jointly certify about 80% of all organic farmers (b) Details about 321 deregistered farmers from one of the certification bodies (c) Personal semi-structured interviews with farmers who deregistered between 2000 and 2003	(a) Detailed data about 176 reverted farmers (b) Personal interviews with 22 reverted farmers	Descriptive analyses	• Lacking demand • Low producer prices • Negative experience with certification and control • Production problems
USA I[13]	?	Analysis of annual registration forms for organic farmers in California from 1992 to 1997	796–1198 registrants per year	Random utility model	• Higher probability for specialized farms to deregister

USA II[48]	2003	Telephone interviews with experts and with conventional and mixed (conventional and organic) farmers and with farmers who had reverted until 2002 in California	30 experts 30 conventional farmers 20 farmers with mixed cultivation 20 reverted farmers	Descriptive analyses	• High production costs • Low yields • Poor quality • High labor costs • Weeds • Marketing problems • Small quantities
USA III[14,49]	2007	(a) Semi-structured telephone interviews with farmers who deregistered between 2003 and 2005 in California (b) Mail survey with 501 farmers who had deregistered between 2003 and 2005 (107 responses)	(a) 21 farmers (b) 77 deregistered farmers	Descriptive analysis Cross tabulation	• Regulatory issues • Issues unrelated to organic production • Production issues • Market issues • Management issues • Price issues

Deregistered: farmers who quit organic farming but it is unknown whether they quit farming altogether or continued with conventional farming.
Reverted: farmers who quit organic farming and continued with conventional farming.

Flaten et al. (Denmark[10]) found that specialized farms generally had more economic problems and a higher likelihood to revert than diversified farms. Risgaard et al. (Denmark[33]) explained that marketing of organic products was much more challenging than that of conventional products and therefore an organic farmer needed to be interested not only in producing but also in marketing his products.

Certification and standards. Difficulties with certification, control and organic standards are also the major reasons for reversion. Obviously, regulations as well as certification and control processes vary between different systems, even within the EU. Nevertheless, many similarities were found regarding farmers' perception of certification, standards and control. In Austria, for example, these problems were the second most important reason after economic aspects[27]. The economic aspect of certification and control, namely the certification and control costs, were also very important in some cases (United Kingdom[47] and Switzerland[44]). The burden of fixed control and certification costs can be a problem especially for small farms (Austria[31] and United Kingdom[46]).

Many farmers complained about a huge amount of bureaucracy when asked about the certification and control process (Austria[27], Denmark[8], Estonia[34] and Norway[10,40]). According to Darnhofer et al. (Austria[7]), farmers also perceive the everyday documentation of procedures as too complex. Besides, farmers criticized frequent changes in organic regulations and necessary adaptations they have to make to conform to regulations (Austria[7], Norway[10] and Switzerland[44]). The frequent changes resulted in insecurity and frustration (Austria[27,31] and Denmark[8]), especially when farmers perceived the alterations to be scientifically unjustified (Norway[37]). In addition to the overall unpredictable political framework, organic farmers felt that the security of their future income was at risk. Changing regulations can cause enormous difficulties, in particular for organic farms with animal husbandry, especially in cases when the modification of stables necessitates high and long-term investments (Austria[31], Estonia[34] and Norway[37]).

Many farmers complained about very strict or highly complicated regulations that are hard to fulfill (Austria[27], Norway[10], Switzerland[44] and United Kingdom[47]). Others generally did not like their farms to be inspected (Austria[7,31]). One of the main reasons for farmers to revert in the United Kingdom was negative experience with the certification and control process[47]. In Denmark, farmers said that dissatisfaction with control procedures was not generally a reason for reversion, it was only in those cases when the inspector was too strict[32].

Furthermore, for many farmers the commitment to the certification period of 5 years (as stated by organic EU-Regulations in order to receive organic subsidies) was too long, and farmers wanted more flexibility. Some stated that the first 5-year period was acceptable, but the

commitment to the next 5 years was too much (Austria[31] and Denmark[8]). Generally, there is a higher likelihood to revert after the first 5-year period than during the first 5 years, otherwise farmers would have to reimburse the subsidies received (Ireland[9]).

Production techniques. Problems regarding organic production techniques were mentioned frequently in the analyzed studies, but interestingly, they only played a minor role in most cases (e.g., Austria[27,31]). A Danish publication even stated that problems regarding production techniques cannot be viewed as an important reason for reversion[33]. Nevertheless, several authors pointed out some problems with organic plant production and animal husbandry that led to reversions. Rigby et al. (United Kingdom[46]), for example, mentioned problems with production techniques especially with access to technical information. Ploomi et al. (Estonia[34]) stated that, as organic cultivation required more knowledge, the lack of special knowledge about organic production methods sometimes led to problems.

The major difficulties named by farmers regarding plant production were weeds (Austria[27], Norway[37] and Switzerland[43]), phytosanitary problems (Estonia[34]) as well as sufficient nutrient supply for the cultivated plants (Norway[50]). These problems resulted in low yields (Norway[10]) or poor quality due to which the products were not marketable. Nevertheless, the agricultural consultants in Denmark mentioned that weeds were not as problematic as the farmers anticipated before the conversion to organic farming. Interestingly, Kaltoft and Risgaard[8,32] reported in their qualitative study that Danish farmers did not intend using pesticides after resuming conventional farming. Nevertheless, some farmers outsourced spraying to avoid doing it themselves.

In animal husbandry, the major difficulties were access to sufficient amounts of organic litter and fodder (e.g., Switzerland[43]). In Norway, obtaining enough straw for litter was a problem because many organic farms are not located in regions where most of the grain is cultivated. These farms often had difficulties in obtaining enough organic feed grain as well. The necessity to feed 100% organic fodder and the obligation to build free stall barns led to reversions especially for organic dairy farms, because they did not receive premium prices for their milk[37].

Macro environment. In several studies it was found that the macro environment of the farm poses difficulties, especially regarding production and marketing of organic products. Large organic processors in Denmark (e.g., mills) were too far away from the producers and did not accept small quantities, which resulted in farmers selling their produce to smaller, local conventional mills[8,32]. Rigby et al.[46] mentioned the same problem in the United Kingdom, where long distances to wholesalers and processors, like abattoirs or packers, proved to be a problem. Schmid[31] found that good regional infrastructure for marketing organic products resulted in more organic farms in Austria, whereas in regions with poor infrastructure there were large numbers of reversions. Some farmers in the United Kingdom who reverted mentioned a general lack of demand for their organic products[47]. In Norway, especially vegetables were difficult to market locally at a premium[37].

In Denmark, the scarcity of agricultural land sometimes resulted in reversion. When farmers wanted to grow and intended to increase their herd size, they needed access to more land. In cases where it was not possible to expand, the decision was between staying organic without increasing herd size or growing and reverting to conventional production, because the existing acreage was not sufficient to fulfill the organic regulations or to produce enough organic fodder[8].

Conclusions

Although several studies with the focus on organic farmers reverting to conventional agriculture already exist, there is still a lack of knowledge regarding this phenomenon. As it appears, there is neither a uniform pattern of steady increase or decrease in the number of organic farms per country, nor certain years in which large-scale deregistration occurred in several countries simultaneously. It would be of great interest to divulge the reasons behind different phenomena in the respective countries or via a cross-country research project.

Obviously, the farmers' reasons for reversion depend on the specific situation in each country. Nevertheless, there are many similarities and common reasons for reverting to conventional agriculture. In general, the literature review gives the impression of unmet expectations in several fields. Apparently, the farmers' expectations regarding economic performance, implications of the certification and control system as well as the adoption of organic management techniques may differ considerably from reality. More research is needed to explore whether better preparation and more information on various aspects of organic farming and marketing before conversion could contribute to lower reversion rates and the form in which this information should be communicated.

Although the final causes for reversion are manifold and most farmers stated a combination of reasons for reversion, the literature review shows that economic problems are the crucial factor in most cases. If frustration with the economic performance of organic management is the main reason for reversion, it seems likely that for these farmers economic motives played a major role in the decision to convert to organic farming as well. It remains to be investigated whether the farmers who claim to have converted mainly out of other, non-economic motivations (see Table 3), are more likely to continue organic farming despite economic difficulties.

Likewise, an analysis of the utility of converting to organic farming and reverting to conventional farming in

relation to economic aspects would give further insights into the decision-making process. Hence, it could be determined whether the decision to revert is mainly due to unmet economic expectations or appears to be an economic necessity in order to maintain the farming business. To this effect, an objective evaluation of the economic situation of organic and reverted farms and their actual market environment (regarding marketing, processing, prices, subsidies, etc.) presents a possibility for further research[51–55].

Another frequently mentioned difficulty apparently was the problematic and interfering bureaucracy which farmers encounter with organic certification[56]. Considering that many reverted farmers plan to continue using organic farming methods without certification, which subsequently results in not being able to market their products as organic products and therefore not receiving premium prices or organic subsidies[10], the burden farmers associate with documentation and control should not be underestimated. Legislation bodies and certification organizations should contemplate measures regarding bureaucratic redtape which may help reduce or at least simplify the procedures involved.

The theoretical model suggests that an evaluation of the possible future utility of organic and conventional management also contributes to the decision to revert. In this context, the role of private or official advisory services becomes apparent. It needs to be further investigated to what extent professional consultation and guidance could influence and improve the future prospects of organic management. As already mentioned by Reissig et al.[42], control on organic farms could not only be used to critically supervise farming practices but also establish better contact and offer support and suggestions for improvement.

The institutions concerned with organic legislations should also ensure stable and predictable regulations for the future[45]. The uncertainty that farmers associate with organic regulations leads to a higher risk perception regarding future organic management compared with the conventional alternative. Any changes should therefore be announced in advance to enable the farmers to implement the changes, especially in cases when considerable investments are required (e.g., regarding animal husbandry).

Access to land is another important key issue, which will have an increasing impact on the relative utility of organic management in the future. In the past few years, high prices of land tenure (as a result of high prices for energy crops) were an impediment for organic farmers to develop their farms in Germany[57] as well as in other countries as well[8]. The energy farmers are capable of paying much higher prices and might easily outplay the organic farmers when it comes to land tenure. If an investment into the production of renewable energies is economically much more promising than organic production, farmers might be tempted to revert to conventional agriculture and to turn to production of energy crops instead. As long as there is heavy governmental support for renewable energy sources, resulting in a much higher expected utility of conventional farming compared with organic farming, this might be counterproductive for the expansion of organic agriculture.

Considering the attempts of many governments to support the expansion of organic farming area by offering attractive subsidies for conversion, and considering the large dropout rates in many countries, it seems promising to take measures to prevent organic farmers from reverting rather than merely trying to recruit new ones[10]. More knowledge is necessary to ascertain why farmers' expectations are not fulfilled, especially with regard to the loss of transaction costs for first converting to organic and later reverting to conventional agriculture. More research is also needed regarding the consequences of possible negative impact of the word of mouth communication of reverted farmers on the image of organic farming and the effects of reverting farmers on other organic farmers. Besides, discontented organic farmers might prevent conventional farmers from converting to organic farming techniques.

Apparently, the farmers' decision to convert to organic farming is not necessarily a 'fundamental' one-way decision[16,58], but a decision that might be put into question after some years. A comparison between organic farmers deciding to remain organic and farmers choosing to revert with respect to the farms' economic, infrastructural and other relevant circumstances, would give further indications of the critical success factors. A deeper understanding of the influencing factors and changes that are necessary for farmers to remain organic should be an important objective for on-going research. The information could be gained by qualitative research methods such as focus group discussions and expert interviews with representatives of farmers' organizations and advisory services.

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Nitrogen balance as an indicator of environmental impact: Toward sustainable agricultural production

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Abstract

Efficient nutrient use is critical to ensure economical crop production while minimizing the impact of excessive nutrient applications on the environment. Nitrogen (N) is a key component of agricultural production, both as an input to support crop production and as a waste product of livestock production. Increasing concern for future sustainability of agricultural production and preservation of the natural resource base has led to the development of nutrient budgets as indicators and policy instruments for nutrient management. Nutrient budgets for N have been developed by the Organization for Economic Co-operation and Development (OECD) as agri-environmental indicators to compare the evolving conditions in member states, and are also used by the US Department of Agriculture Natural Resource Conservation Service (USDA-NRCS) to develop nutrient management plans. Here, we examine the crop and animal production systems, drivers impacting management choices, and the outcome of those choices to assess the utility of gross annual N balances in tracking the progress of management decisions in minimizing the environmental impact of agricultural production systems. We use as case studies two very different agronomic production systems: Mississippi, USA and Poland. State and country level data from the US Department of Agriculture and OECD databases are used to develop data for the years 1998–2008, and gross annual N balances are computed. Examination of agricultural production practices reveals that the gross annual N balance is a useful tool in identifying differences in the magnitude and trends in N within agricultural systems over large areas. Significant differences in the magnitude of the N budget were observed between the highly diversified, small-scale agriculture common to Poland, and the large-scale, intensive agriculture of Mississippi. It is noted that use of N balance indices can be problematic if the primary intent is to reveal the impact of economic drivers, such as crop prices, or management choices, such as tillage or crop rotation. Changes in cropping systems in response to commodity prices that improve N balance can be masked by detrimental growing conditions, including edaphic, biotic and weather conditions, that are outside of the producers' control. Moreover, use of large area-scale indices such as country or state-wide balances may mask the severity of localized nutrient imbalances that result from regionalized production systems that overwhelm the nutrient balance, such as confinement livestock production. Development of a policy to address environmental impact and establish sustainable production systems must consider the year-to-year variability of drivers impacting agricultural production, and the spatial heterogeneity of nutrient imbalance.

Key words: agricultural production, gross annual nitrogen balance, agricultural sustainability, environmental indicators

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Introduction

Achieving sustainable agronomic production requires balancing nutrient inputs to the system with outputs harvested from, generated by or transported out of the system. Continued overproduction can deplete soil and water resources. Similarly, development of contaminants and waste in excess of what the system metabolizes can result in pollution of the immediate agricultural system and downstream environments.

Current agricultural production systems have developed in response to social, political, economic, environmental and technological drivers that operate both internal and external to agriculture[1]. These drivers influence management choices throughout the production cycle, including the types of crops and animals grown, the production methods used, harvesting, processing and marketing.

The predominant agricultural systems in the US have expanded to capture 'economies of scale'[2]. These large-scale production systems, such as intensive monocrop or confinement animal production systems, have also become highly specialized[3], improving operational efficiency and meeting consumer demands for consistent, inexpensive products. Processing and distribution networks, along with vertical integration of agricultural production systems, have resulted in geographic specialization[4]. Far from benefiting farmers, these technological advances have intensified production and the complexity of the US farming system, increased our dependence on soil and water resources and fossil fuels, entrapped farmers in a technology treadmill, and, in some cases, decreased control by producers[5]. They have also resulted in local and regional water quality problems, ranging in scale from polluted stock ponds and small streams to the hypoxia in the northern Gulf of Mexico.

The agricultural systems in Central Eastern Europe have also experienced profound changes with the abrupt end of the planned economy era in the early 1990s[6]. With the end of subsidized agricultural inputs, fertilizer use decreased, negatively impacting crop yield[7]. Animal production was also impacted with the collapse of many state-owned meat processors and their replacement with small, privately owned companies[8]. To remain profitable, meat production in Poland has increasingly moved toward large-scale confinement animal systems instead of pastured animal production systems[9]. The regionalization and specialization of industrial agriculture increased negative environmental impact in other countries[10], raising concerns that similar impact is or will be occurring in Poland. However, while traditional Polish agricultural systems that integrated animal and crop production have the potential to improve the environmental impact of agriculture, they may limit the nutrients needed for adequate crop production[11]. Some ongoing assessment that could reveal the emerging environmental impact is clearly desirable and is the intent of many current environmental policies.

Nitrogen is a key component of agricultural production systems—both in its use as a fertilizer for crop production and as a byproduct of livestock systems. Sustainable agronomic production depends on the environmentally beneficial management of nitrogen within the system. Nitrogen fertilizer is often used excessively to ensure high crop yield, particularly when the anticipated returns are high due to higher commodity prices[12]. Application of N in excess of what can be used by the plants results in negative economic consequences for the producer and potential contamination of the environment. Animal production systems that confine many animals to small areas create regions of concentrated nitrogenous waste, with potential impairment of local and downstream soil and water qualities.

Increased problems with N in the environment have led to implementation of controls in Europe and America. One common method of evaluating nutrient release from agricultural operations is calculation of the nutrient balance as proposed by the Organization for Economic Co-operation and Development (OECD)[13]. Nutrient balance is defined as the difference between the inputs to the system and the outputs harvested from the system for the total agricultural land area in production[13]. The nutrient balance is intended to be an indicator of the amount of excess nutrient applied to the system that is not captured in harvested product, and hence is a potential pollutant from the system[14]. Element and nutrient balances have become widely adopted tools to quantify the impact of agriculture on the environment, and establish a monetary value for natural resources and improvements in management practices. These measures and valuation are expected to be important components in the effort to transition agriculture toward sustainability, but wide differences exist in their construction and application. These differences raise the question as to whether such balance-derived indices actually reveal net year to year changes in the state of the environment on local scales, or are useful in discerning the impact of policy-induced changes in agricultural management.

At the national level, element balances have been implemented in the European community as tools to meet environmental targets for nutrient management in agriculture, either on a voluntary or a mandatory basis. Several EU directives, policies and measures provide incentives to agriculture to decrease its burden on the environment[15,16]. The US Department of Agriculture Natural Resource Conservation Service (USDA-NRCS) conservation programs, tied with direct payments to farmers, are developed to enhance adoption of environmentally friendly management practices[17]. The challenge is to reduce the nutrient imbalance as much as possible by reducing excessive production of nutrients within the system and improving nutrient use efficiency on-farm through better crop production and management practices[18,19,20]. Attention must also be paid to the varied temporal and spatial scales of nutrient loss and their

impact on the environment[11]. An additional challenge is to address unique regional and national goals for both production and environmental quality using common indices.

To balance the agricultural system, improving production and profitability while limiting negative impact on the environment, we need to fully understand all the factors contributing to nitrogen utilization and the nitrogen cycle within the agricultural production system. Here, we examine agricultural production systems in Poland and Mississippi, USA as case studies to explore the drivers impacting management practices. The opportunity to examine these very divergent agricultural systems arose through a collaborative research program supported monetarily through the OECD. The goal of this research is to determine the impact of management practices, changes in crop and animal systems, and integration of production on nutrient balances. We use nitrogen balance as a measure of the sustainability of these production systems, since N has been identified as a key element in assessing the impact of agriculture on the environment[14]. The data and analysis reported indicate the utility of gross annual nutrient budgets in identifying trends in nutrient balances for large areas. The data raise some questions, however, as to whether spatial scale issues and annual variability in crop productivity levels are obscuring changes in nutrient balance arising from altered production practices.

Materials and Methods

Assessment of agriculture

Data on crop and animal production, crop area planted and harvested, total and per hectare yield, and price received by farmers were calculated from farmers' records as reported by the National Agricultural Statistics Service (NASS)[21] and the Food and Agriculture Organization Statistics (FAOSTAT)[22]. Livestock numbers were based on number of animals in each size category reported by NASS[21] for Mississippi and Glowny[23] and FAOSTAT[22] for Poland. Slaughter records were used to estimate livestock numbers for those animals having more than one production cycle in a year, such as poultry and swine. Agricultural prices in dollars were used to standardize the comparison between countries.

Weather information from primary production regions of each area was used for information on weather during the study period. The Delta Research and Extension Center maintains a network of weather stations throughout the state[24]. The primary weather station at Stoneville, Mississippi has been collecting weather information on precipitation and rainfall since 1930. Because of the completeness and accuracy of the weather information, this site was used for weather information from Mississippi. Weather information from Poland is collected at nine locations, but only two stations are currently publically available[25,26]. The weather station at Siedlce, Poland, was selected to summarize the weather information as it was closest to the principal agricultural regions of Poland. Forty-five years (1966–2010) of complete weather data are publically available from the weather station at Siedlce, Poland[25]. For comparison, we used the same time period of weather data from Stoneville, Mississippi. Cumulative growing degree days (GDDs) are a method of estimating crop production potential. Annual cumulative GDDs above 10 °C were calculated to compare annual temperature between the two regions over the course of the study period. Although it is recognized that a common GDD is not appropriate to crops in both climates, a single GDD definition was used for consistency in comparing the two regions. Total annual rainfall was calculated from reported rainfall values at the two stations.

Mississippi has more than 12 M ha of land, the majority of which (61%) is forested[27]. Pasture and cropland account for an additional 27% (3.3 M ha) of the land. As with other US states, recreational and hobby farms account for a portion of the farmland; these were excluded from this study. The average individual production farm size in Mississippi is more than 110 ha. Large-scale production agriculture predominates, with the majority of tilled hectares planted in soybeans, corn and cotton. Crop production in Mississippi is primarily concentrated in the Mississippi Valley alluvial flood plain, commonly called the Delta, located in the northwestern portion of the state[27]. Most livestock production, particularly confinement poultry production, occurs in the central and southern regions of the state[28].

In Mississippi, cereals comprise mainly wheat (winter), rice, corn and sorghum. Oil crops include predominantly soybeans, but also peanuts (ground nuts) and cotton seed; root crops are sweet potatoes. Harvested fodder includes maize and sorghum harvested for silage; hay is also grown, but total yield and hectarage may be underreported. Cotton is grown primarily for lint production. Vegetables and melons, fruits (blueberries) and nuts (pecans) are also grown, but on a very small portion of the land.

Nearly 60% of the land area in Poland is devoted to crop and animal production, and arable land and grassland account for 18 M ha. Most farms are small and semi-subsistence farms of 1–5 ha total land area, especially in the eastern part of the country, as Poland was never fully collectivized prior to 1990[29]. These farms use a minimum of purchased farm inputs (e.g., pesticides, energy and water), and farm income is insufficient to support modernization of the farming enterprise. The highest area of arable land in Poland is sown in cereals, potatoes, rapeseed and fodder.

For Poland, cereals include spring and winter wheat, rye, barley, triticale, oats, maize, and minor hectarage of other cereals such as buckwheat and millet. Oil crops are predominantly rapeseed and minor areas planted to other oil crops such as sunflower seed and hemp seed. Dried

pulses and beans are also planted. Potatoes are the predominant root crop. Vegetables and citrus fruits are also reported. Vegetable and other root crop production includes cabbages and brassicas, carrots, turnips, tomatoes, beans (green, string and dry), peas (green and dry), cucumbers and gherkins, onions, leeks and other alliaceous vegetables, asparagus, lettuce and chicory, pumpkins, squash and gourd. Fruit and nuts produced in Poland include strawberries, apples, cherries, currant, plums and sloes, lupines, raspberries, pears, blueberries, gooseberries, apricots, peaches, berries, hazelnuts and walnuts. Industrial crops include primarily sugar beet, and minor areas of flax and hemp fiber and tow, tobacco, chicory, linseed and hops. Beets are harvested both for sugar production and for fodder. Green fodder is primarily clover and maize cut for silage. Permanent pasture and the estimate of yield from permanent pasture are reported, with the assumption that 100% of the permanent pasture is consumed[30]. Crop residue includes head, leaves and stems, straw, as well as other crop residues.

Development of nitrogen budgets

A methodology for calculating soil nutrient balances has been developed by the OECD[13] and adopted by Eurostat[30]. The method was used to calculate gross annual soil nitrogen (N) balance per hectare for Poland and Mississippi for the years 1998–2008. The gross annual nitrogen balance is defined as the difference between total N inputs less total N outputs for the system, for the total agricultural area (excluding forested and non-agricultural lands).

Total N inputs included: fertilizers, both inorganic (usually purchased) and organic, excluding animal manure; livestock manure; biological N fixation; atmospheric deposition of N compounds; and other inputs (seed, planting material, etc.). Inorganic fertilizer amounts were obtained from FAOSTAT[22] and IFADATA[31] for Poland, and from NASS[21] for Mississippi. Information on total crop harvested biomass was obtained from FAOSTAT[22], Glowny[23], and NASS[21] databases (multiple years). Animal production records were used to estimate manure production as outlined in the OECD procedure[13]. Livestock records were obtained from Glowny[23] and FAOSTAT[22] for Poland, and NASS[21] for Mississippi. Coefficients were used to convert livestock numbers into manure quantity and the content and composition of total N from livestock was calculated. Coefficients for conversion of livestock manure were obtained from Meisinger and Randell[32], IUNG-PIB[33], or Eurostat[30]. Biological nitrogen conversion is based on leguminous crops. Atmospheric deposition is calculated based on atmospheric deposition to total agricultural land[13]. Inputs to the agricultural system from seeds and other planting materials are calculated from beginning amounts of planting materials, multiplied by a crop-specific coefficient of N content[13].

The total N outputs were measured as N used within the agricultural system, and included all harvested crop parts, including fodder crops, non-marketed fodder crops and grass (harvested and grazed). The nitrogen content of harvested biomass is determined by multiplying the harvested biomass by a crop-specific coefficient[13]. Coefficients to convert plant biomass into nutrient uptake and N composition were obtained from Eurostat[30], Meisinger and Randell[32], or IUNG-PIB[33].

Total nitrogen input to the system and total nitrogen used within the agricultural production system were determined from the total crop and animal production. Gross annual nitrogen balance was determined as the difference between total nitrogen output by crops and forage and the total nitrogen input from fertilizer, livestock manure, and other nitrogen inputs on a land area basis[13].

Results

Crop production

Changes in agricultural production systems—the crops and animals produced—are the primary factors regulating nitrogen budget. The types of crops that can be produced in an area are dependent in part on the weather conditions. Mississippi has a hot, wet climate with an average annual rainfall of 135 ± 26 cm (average $\pm$ SD). For Mississippi, the average cumulative GDDs above 10 °C for the period of study were 3351 ± 136 (average $\pm$ SD). Crop production in Mississippi is more often limited by excessive temperature, and can be limited by either too much or too little rainfall. In comparison, Poland has a continental climate, with much less average annual rainfall (54.7 ± 9.3 cm; average $\pm$ SD) and significantly fewer cumulative annual GDDs above 10 °C (1037 ± 96; average $\pm$ SD).[25,26] Crop production in Poland is most commonly limited by low temperatures and too little rainfall, although flooding does occur.

Crop production hectarage in Mississippi showed substantial year-to-year variability, with fewer varieties of crops produced than in Poland (Figs. 1A and 2A). While the smaller diversity in types of crops produced somewhat reflects the industrial production system predominant in the US, it also arises from the fact that crop production reports are voluntary for non-program crops. Hence, while vegetables, fruits, nuts and hay are grown in Mississippi[21], they are not covered by support programs, resulting in a likely underreporting of the area planted. Soybeans and cotton were the two most commonly planted crops, showing an inverse relationship in hectares planted (Fig. 1A). Soybean hectares ranged from a low of 25% to a high of nearly 50% of crop land. Cotton, long considered 'King' of the Mid-South, fell rapidly from a high near 40% of the area planted in 2001, to a record low

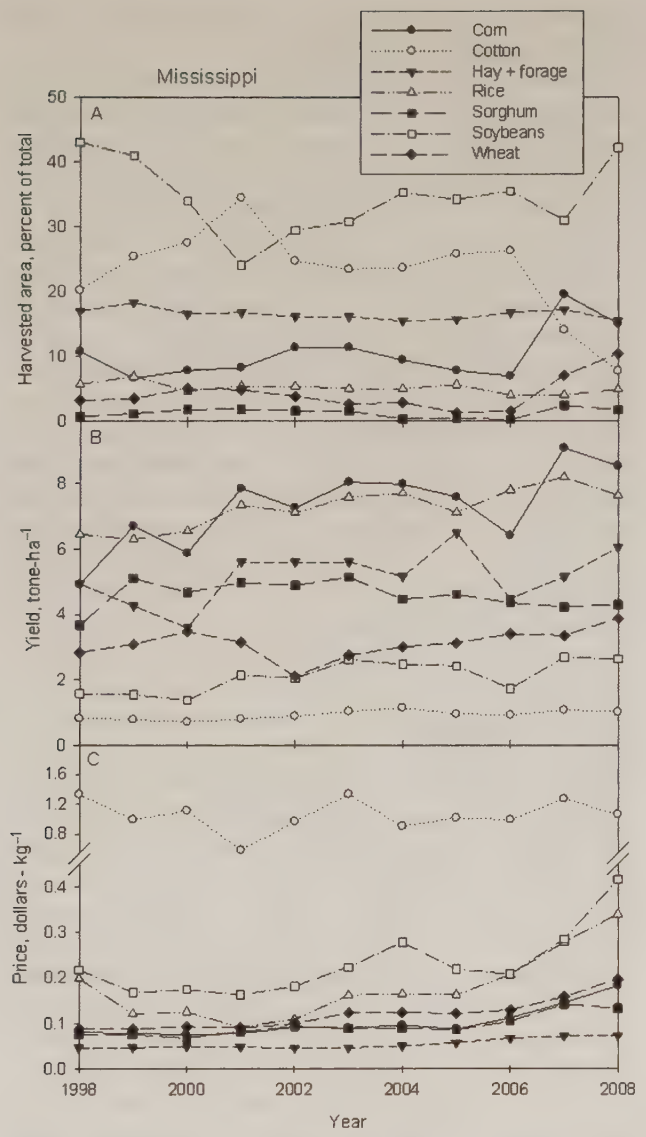

Figure 1. Changes in crop planting (A), crop yield (B), and prices received (C) in Mississippi, 1998–2008; note the break and change in scale on the vertical axis in (C).

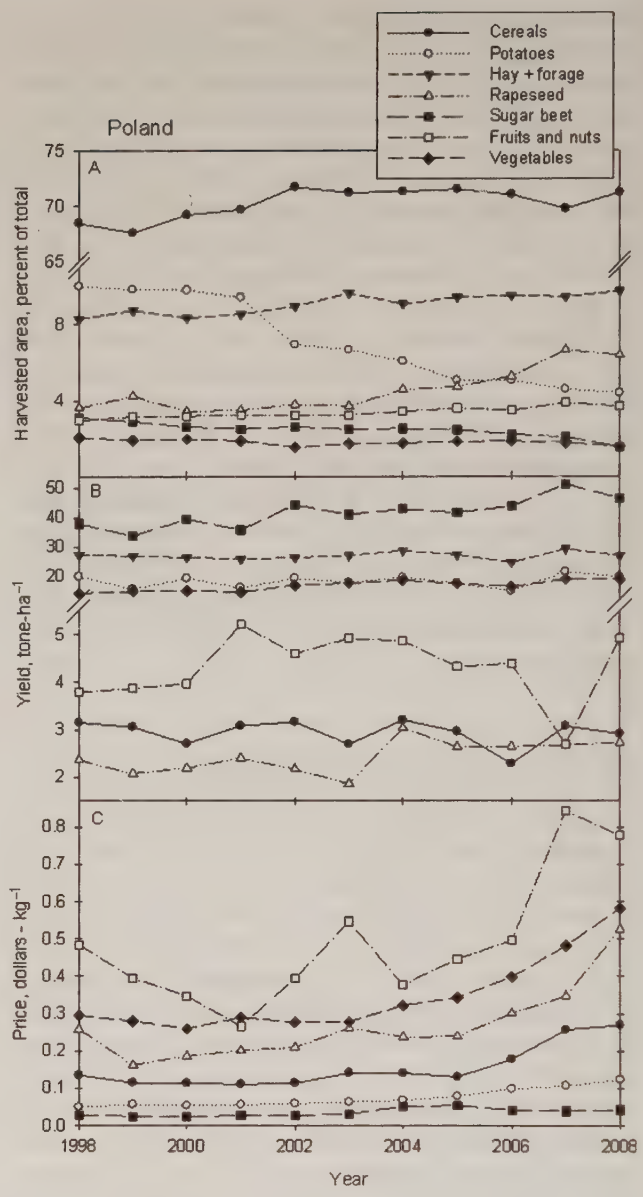

Figure 2. Changes in crop planting (A), crop yield (B), and prices received (C) in Poland from 1998 to 2008; note the break and change in scale on the vertical axes in (A) and (B).

of less than 10% in 2008. While commonly considered to have initiated the loss of cotton hectarage in the Mid-South[34], in Mississippi the increase in area planted to corn only accounted for the reduced cotton hectarage in 2007. Soybeans were the primary crop grown instead of cotton, and corn hectares declined after the strong increase in 2007. Sorghum hectarage also showed a strong increase in 2007, although total area planted to sorghum accounts for only a small portion (less than 2.5%) of total crop land. Hay (16%) and rice (5%) production showed only minor changes in the planted area. Wheat is grown as winter wheat, commonly in a two-year rotation of corn (March–August), winter wheat (October–June) and soybeans (June–September), and hence represents a second crop harvested within 1 year. Wheat production remained steady at around 3% of production area, but more than doubled in 2007 (7%) and 2008 to 10% of hectarage. The increased area planted to wheat in 2007 and 2008 coincided with the increase in corn and soybean hectarage and loss of cotton area. Other crops, including peanuts, sweet potatoes and vegetables, each accounted for less than 1% of the reported hectares planted.

Crop yields showed distinct changes with year in Mississippi (Fig. 1B). Corn yield increased more than 70% over the 11-year period, from 4.9 metric tons-ha^{-1} to 8.5 tons-ha^{-1}. Similarly, soybean yield increased almost 70%, from 1.6 to 2.6 tons-ha^{-1}. Rice, hay and wheat yield improvements were more modest, ranging from 37% increase for wheat, 22% increase for hay and 18% increase for rice. Cotton and sorghum yields remained nearly steady throughout the 11-year study period.

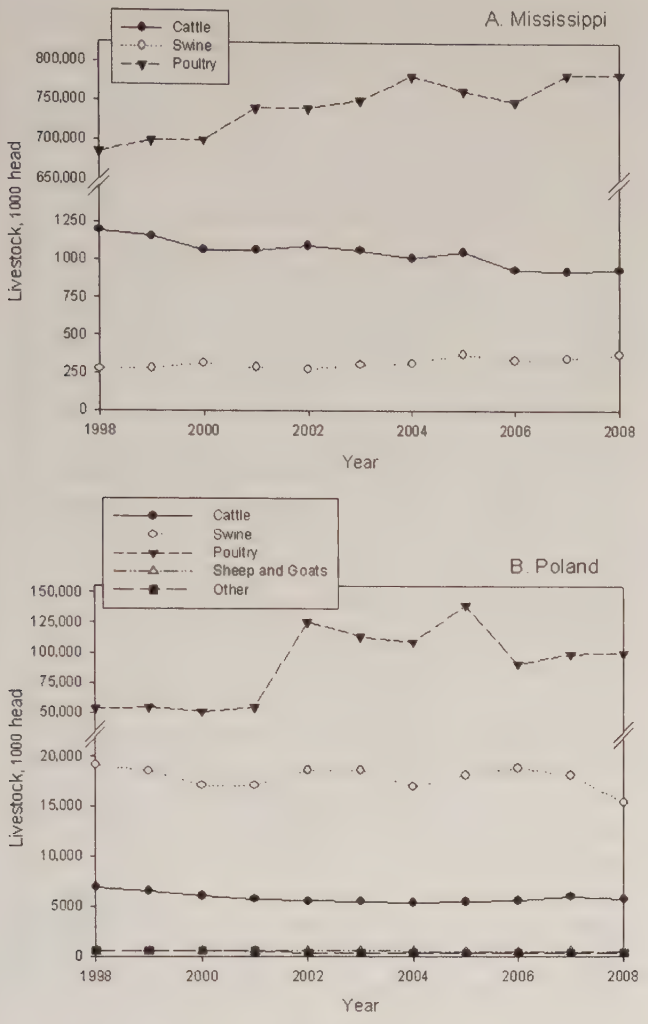

Figure 3. Changes in animal production and livestock in Mississippi (A) and Poland (B) from 1998 to 2008, 1000 head; note the break and change in scale on the vertical axes in both figures.

Crop production is dependent on a variety of environmental conditions experienced during the growing season, including edaphic, biotic and weather conditions. In 2000, yields were reduced for corn (20%), hay and forage (30%), and soybean (34%) from the observed average yields for the 11-year period (Fig. 1B). In 2006, yields were similarly reduced in corn, hay and forage, and soybeans. Wheat yield decreased more than 30% of the average in 2002. Cotton yield remained steady throughout the period, showing a 20% loss of yield in 2000 only, and a slight yield increase in 2006. Sorghum yields were reduced only 5% from average in 2006, and showed a 2% increase in 2000.

Cropping decisions—which crop or animal to produce—are based on anticipated economic return in some crops in Mississippi (Fig. 1C). The land area planted to corn and soybean increased in response to commodity price increase after 2006. These crops replaced cotton. Other crops, most notably rice and hay, did not respond to price fluctuations (Fig. 1C). For these crops, the field conditions may determine cropping decisions. For example, rice in Mississippi is usually flooded for weed control[35]. This limits rice production to soil types that will hold a flood for a sufficient length of time to reduce weed pressure, and hence, limits the distribution of rice planting to fields with slowly draining soils. Similarly, pastures are more common in the hilly portion of the state[27]. Terrain and lack of adequate irrigation resources may limit the conversion of pastures into row crop production.

The cropping systems in Poland remained relatively stable over the time period reported in this study (Fig. 2A). While a variety of crops are grown in Poland, the predominant crops are cereals, accounting for around 70% of the cropland. Wheat and triticale were planted in the largest percent hectarage, increasing from 25 to 30% of the planted area over the 11-year period of study (data not shown). Rye hectarage declined over the time period, with a concomitant rise in other mixed grains, most notably maize. Barley production showed only a modest increase in area planted over the 11-year period, along with forage and silage (maize, legumes, clover, vegetable roots and alfalfa). Potato production declined from 10 to 5% of hectarage, a trend which has been evident throughout the potato-growing regions of Europe since 1960 and reflects changes in animal and human diets with societal modernization[36]. Vegetable, fruit and nut production remained nearly steady at 5% of all hectares planted. The number of planted hectares of rapeseed increased slightly during the period of study.

Crop yields remained steady for hay, forage and silage in Poland over the study period (Fig. 2B). Yields were reduced around 15% for potatoes and sugar beet in 1999 and 2001 from the average observed, and increased nearly 20% above average for potatoes and sugar beet in 2007. Average yield of all cereals showed total yield declines of around 20% in 2006, with more moderate yield losses in 2000 and 2003, primarily due to drought[37,38]. Average cereal yields in Poland were similar to those observed for wheat in Mississippi. The 38% loss of fruit yield in 2007 resulted primarily from the loss of apples, although other fruits also showed reduced yields[22].

With the exception of fruits and vegetables, the price volatility for crops in Poland was much less than that observed in Mississippi (Fig. 2C). Most crop prices remained steady, only showing a substantial increase in price after 2005. Cropping decisions did not respond to price in Poland, with the exception of rapeseed. No prices for silage were reported for Poland since most of it was used on-farm[30].

Animal production

Poultry is the predominant livestock in both Mississippi and Poland (Fig. 3A and B) according to number of animals. However, the methods of production were very different, resulting in significant differences in the number of birds produced. In Mississippi, the predominant

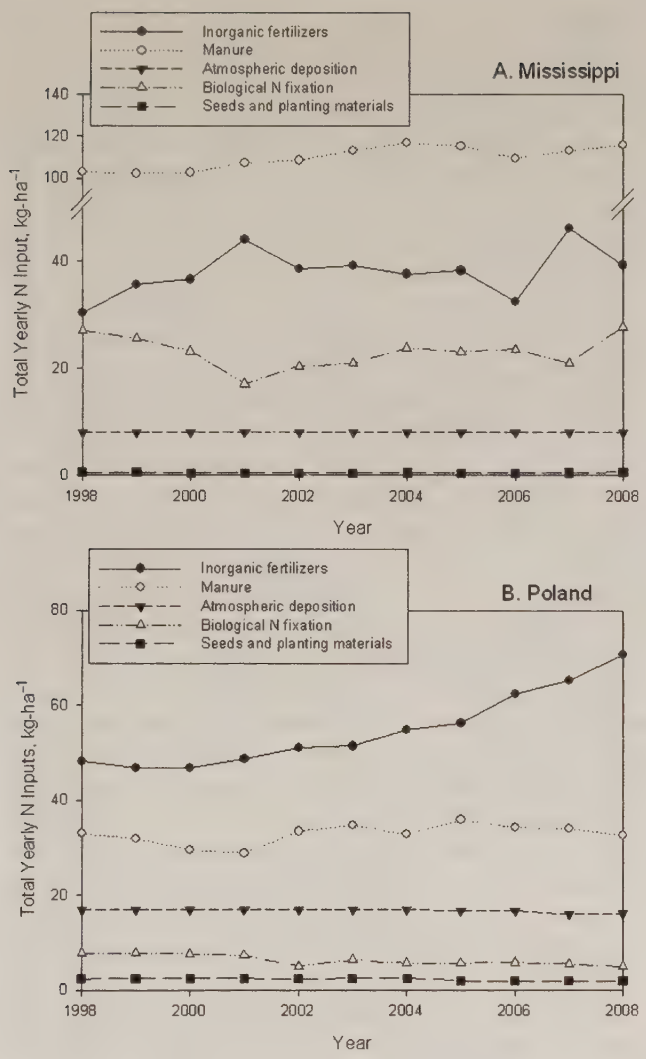

Figure 4. N inputs per hectare of agricultural land from all sources for Mississippi (A) and Poland (B); note the break and change in scale on the vertical axis in (A).

method of poultry production is confinement poultry houses. While some chickens are produced in free-range systems, these contribute only a minor share to total production. There was a steady increase in poultry production for both meat and eggs over the 11-year period, resulting in a net 14% increase in Mississippi. Alternatively, cattle production (primarily for meat production) showed a steady decline of more than 20% from 1,200,000 head to 940,000 head over the study period. Swine production increased steadily over the period, for a net gain of 36%, or 100,000 head.

Poultry production more than doubled in Poland in 2002, for a net increase of 87% over the 11-year period of study. Cattle and pork production declined steadily throughout the period for a net loss of 17% in cattle and 19% in swine. Other animals, such as sheep, goats and other poultry, were produced in minor numbers. Although most animal production in Poland is free-range, confinement animal production systems are being increasingly introduced, especially for swine production[9].

Nitrogen input

Sources of nitrogen into the system were developed from all sources using the OECD methodology[13]. Mineral fertilizer and manure application account for most of the nitrogen inputs (Fig. 4A and B). The inorganic fertilizers and the nutrient content of livestock manure together comprise about 77% of nitrogen inputs for Poland and 83% for Mississippi. Livestock manure accounted for more than 100 kg of nitrogen input per hectare to the agricultural system each year in Mississippi (Fig. 4A), and increased 12% over the study period. The predominant source of this nitrogen is from poultry litter (78%). Cattle are primarily pastured in Mississippi, and produce approximately 60,000 metric tons of N yearly. The large poultry confinement production systems in Mississippi generate substantial waste and most of this waste is spread on pasture, rather than crop fields. The geographic separation of the primary crop production area from the poultry production regions within the state limit the use of poultry litter on crop fields because of the high transportation costs associated with moving the litter to other areas.

Inorganic fertilizers (purchased) in Mississippi accounted for an average of 38 kg-ha^{-1} additional nitrogen inputs for tilled crops (Fig. 4A), and increased nearly 30% over the 11-year study period. Production of corn or cotton instead of soybean (Fig. 1A) resulted in a 15 and 21% increase in inorganic fertilizer use in 2001 and 2007, respectively. Biological nitrogen fixation from soybeans contributed an average of 23 kg N-ha^{-1} annually. Reductions in soybean hectarage in 2001 and 2007 decreased biological nitrogen fixation by 26 and 9% from the average, respectively. Atmospheric deposition and seeds and planting materials contributed only minor amounts to the annual N input in Mississippi.

Almost half of the total N inputs to the agronomic system in Poland arise from purchased fertilizers (inorganic) (Fig. 4B). Over the 11-year period of study, inorganic fertilizer increased more than 45% in Poland, reflecting the transitioning of the agricultural system from the planned economy toward a free-market economy[6]. Livestock manure contributed an additional 33 kg-ha^{-1} on average each year, or 29% of the overall nitrogen budget (Fig. 4B). Cattle and swine constitute the primary manure nitrogen inputs in Poland (Fig. 3B), although the increase in poultry production has increased the contribution of poultry litter to the N balance. Atmospheric deposition and seeds and planting materials contributed only 15 and 2%, respectively, to the overall N inputs, and remained nearly steady. Biological nitrogen fixation accounted for an average of 5% of the total N input, and showed a steady decline in Poland.

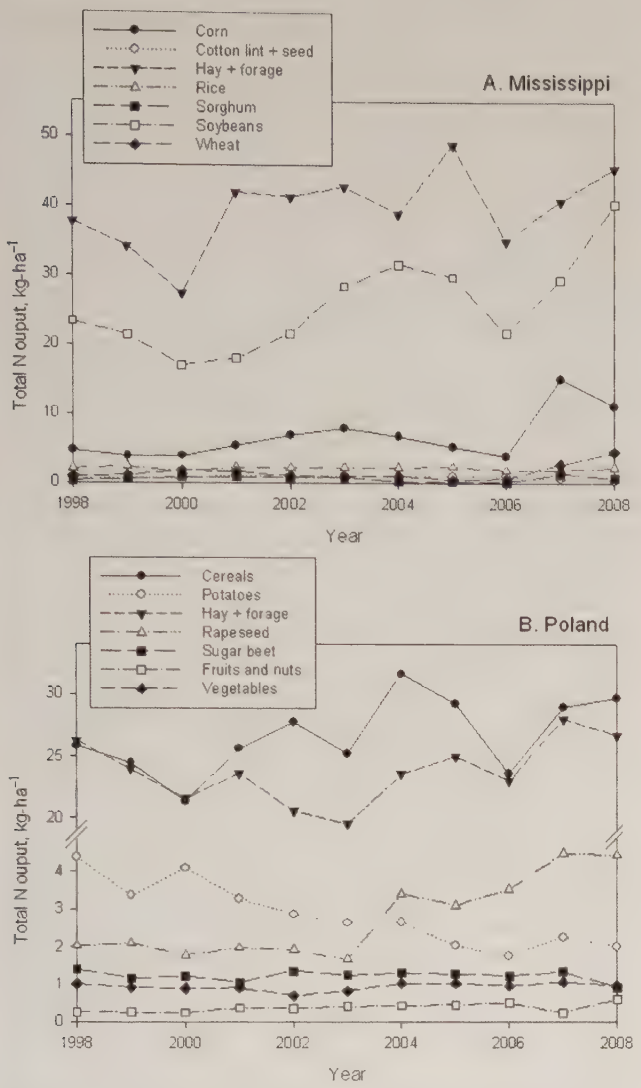

Figure 5. Nitrogen output harvested from crops and forage for Mississippi (A) and Poland (B) from 1998 to 2008; note the break and change in scale on the vertical axis in (B).

In Poland, total nitrogen inputs reached the lowest level of 103 kg N-ha^{-1} in 2000, due primarily to a drop in inorganic fertilizer use and manure production. The decline in manure production reached the lowest level in 2001, reflecting the decline in the swine and cattle herds[8]. Manure production in Poland increased following the resurgence of animal production, primarily poultry, in 2002 (Fig. 4B).

Nitrogen output

Changes in cropping patterns alter the total nitrogen output, or N that is harvested and removed from the agricultural system. Overall, soybeans, hay and forage accounted for 83% of N output per hectare in Mississippi (Fig. 5A). Cereals, including corn, sorghum and wheat, accounted for an additional 14% of N output within the agricultural system in Mississippi. Other crops contributed only a very minor fraction of the total N output. Cereals, hay and forage predominated the N output in Poland, accounting for more than 60% of the total N output (Fig. 5B). The remaining N output was accounted for by a variety of crops.

Nitrogen output is also dependent on crop function, or the biological activity and performance of plants, which impacts the per hectare yield. The loss of crop yield, particularly of corn, soybeans, hay and forage in 2000 and again in 2006 (Fig. 1B) reduced the N output by soybeans (32 and 16%), corn (40 and 43%), and hay and forage (29 and 12%) in Mississippi (Fig. 5A). A similar reduction in crop yield was seen in Poland in 2000, and more strongly in 2003 and 2006, in cereals (15%), rapeseed (30–40%) and potatoes (up to 40%). Because cereals dominate Polish crop production, the poor crop production in cereals in these years had the greatest impact on limiting N output (Fig. 5B).

Nitrogen balance

Trends in annual total nitrogen input, output and balance indicate changes due to management decisions, cultivar differences and variable environmental conditions (Fig. 6). The cropping decision impacts the nitrogen output by crops and forage through the coefficient of conversion of N into crop. Soybeans have the highest conversion coefficient (59 kg N per ton of plant material), followed by pasture (23 kg-t^{-1})[32]. Cereals range from a high of 19 kg-t^{-1} for barley, oats and rye, 18 for millet, 17 for sorghum, triticale and wheat, to a low of 10 kg-t^{-1} for rice. Cotton and sweet potatoes have the lowest conversion coefficients of less than 5 kg-t^{-1} plant material.

Total annual N input to the agricultural system showed a 7% increase in Mississippi over the study period (Fig. 6A) to approximately 600,000 metric tons. The major factor contributing to the net increase of N in the agronomic system was due to the increasing number of livestock produced. The loss of soybean hectarage in 2000 and 2006 resulted in slight ($\sim$ 2.5%) decreases in N inputs. Total annual N output increased steadily, with an overall 43% increase in N output over the 11-year study period in Mississippi. This increase occurred partly because of better crop yields per acre and partly because of a shift in the cropping system toward corn, soybeans and wheat (Fig. 6A). The improved crop uptake was interrupted in 2000 and 2006 because of poor crop productivity levels. These years of crop loss increased the overall N balance in Mississippi 15% above the average in these years.

Total annual N input declined initially in Poland (Fig. 6B) as fewer animals were produced. The resumption of poultry production in 2002 reversed the trend, increasing total inputs to the N budget overall by 5%. As in Mississippi, poor crop yields in 2000, 2003 and 2006 decreased the annual N outputs up to 16%, increasing the annual N balance for Poland. Over the course of the 11-year period, the nitrogen balance in

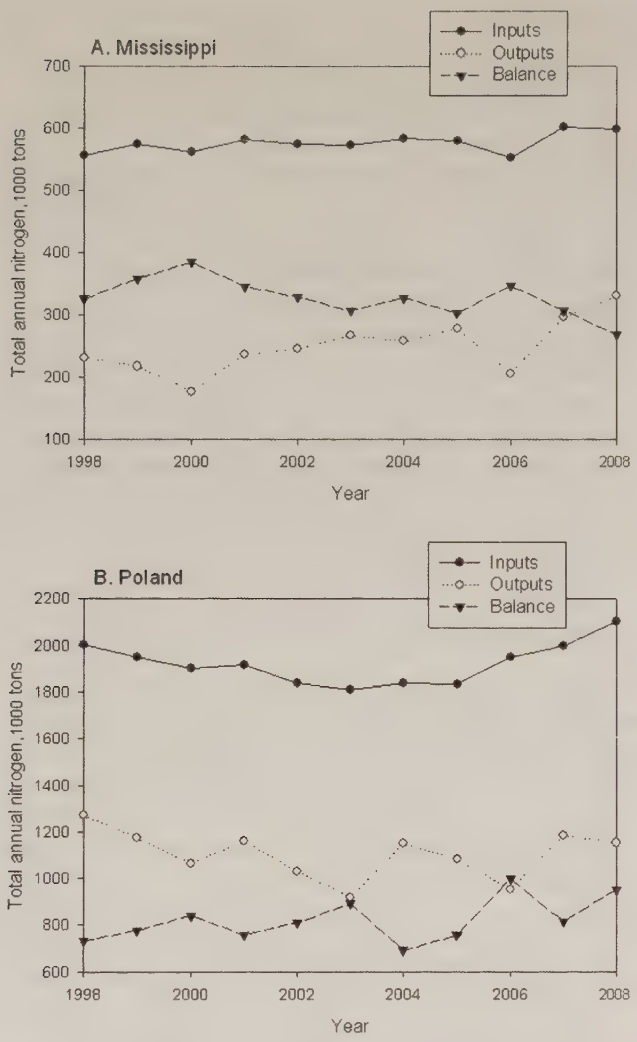

Figure 6. Annual nitrogen budgets, input, output and balance for Mississippi (A) and Poland (B) from 1998 to 2008, 1000 tons.

Poland increased 30% to more than 950,000 metric tons of nitrogen per year.

The gross annual N balance is an agro-environmental indicator used in agro-policy and provides information about the relative utilization of N applied to an agricultural production system of a country and region on a per-hectare basis. The nitrogen balance represents the amount of N applied, produced or fixed within the agronomic system in excess of that harvested from the system. Sustainability of the system is enhanced by reducing the gross annual nitrogen balance, to bring the inputs in line with the outputs.

The gross annual N balance per hectare during the 11-year period averaged 101 kg N-ha^{-1} in Mississippi (Fig. 7). The gross annual N balance decreased steadily, for a total reduction of 11%. Although this is an improvement in the agricultural system, substantially more nitrogen is put into the agricultural system than is harvested from the system. As Mississippi has converted

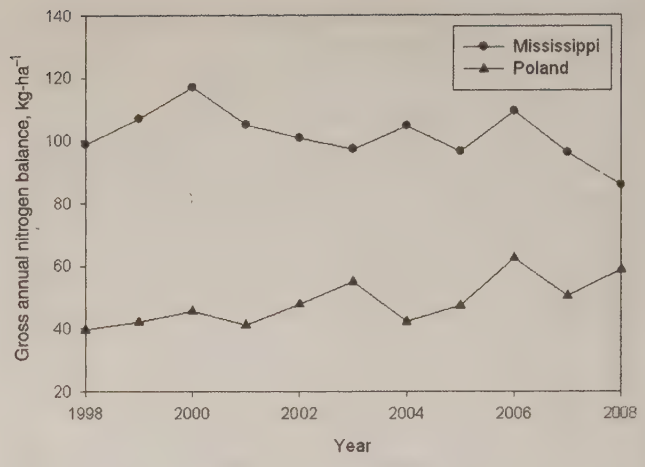

Figure 7. Gross annual nitrogen balance per hectare of agricultural land for Mississippi and Poland from 1998 to 2008.

farmland from cotton to corn and soybeans (Fig. 1), the nitrogen uptake improved (Fig. 6). The increase in area planted to corn and soybean in 2007 and 2008 decreased the gross annual N balance in Mississippi 5 and 15%, respectively, from the 11-year average (Fig. 7).

The gross annual N balance in Poland increased 48% from 39 kg N-ha^{-1} in 1998 to 60 kg N-ha^{-1} in 2008 (Fig. 7). This increase occurred primarily from the greater use of inorganic fertilizers, and secondarily because of increased manure production (Fig. 4B). The gross annual N balance was substantially higher in Mississippi than in Poland, primarily as a result of the high manure production associated with confinement poultry production (Fig. 7).

Years of compromised crop yield significantly impacted the gross annual nitrogen balance in both Mississippi and Poland. Note that for both Poland and Mississippi, adverse weather had a strong impact on N outputs (and hence N budgets) on a year-to-year basis. This impact is sufficient to mask any improvements in N budgets achieved from the changes in cropping systems or management practices, with the exception of confinement livestock production.

The gross annual N balance calculated for Mississippi is overwhelmed by livestock manure production. A significant reduction in poultry production (to one-eighth of the current levels) would be needed to bring the N budget into balance in Mississippi. In the absence of large confinement animal production, the annual gross N is closer to balanced in Poland (Fig. 7). However, the continued increase in inorganic fertilizer use in the absence of additional crop production increased the gross N budget in later years in Poland (Fig. 7). A 10% reduction in purchased fertilizers in concert with a 10% increase in productivity would greatly increase the partial factor productivity of crops with respect to N. In order to balance the gross annual N budget, however, animal production would need to be reduced to 25% of its current level.

Discussion

Agricultural production systems change in response to internal and external influences[39]. Recognition of the need to maintain healthy productive capacity through resilience to these influences has led to the concept of sustainable production systems[40]. Sustainability in agriculture is attained by balancing the inputs to the system with products harvested from or wastes produced by the system, usually focused in three key areas: economic, environmental and social.

The nitrogen cycle is a key aspect of agriculture—impacting both production potential and environmental contamination. Fertilizer contamination has become a key environmental concern because of the impact on large environmental areas due to excessive application and intensive production practices. Primary watersheds in the US are targeting agricultural production practices to manage excess nutrient runoff and reduce contamination of large waterways such as the Gulf of Mexico[41]. Nutrient balances have been identified as a common method to evaluate nutrient release from agricultural operations[13]. The European Union directives have set goals that each member country must abide by to limit nutrient overload[15].

Societal goals engender the development of policy, as well as the creation of monitoring tools to assess compliance with policy. Such tools are based on some understanding of the related physical processes, with varying degrees of sophistication and accuracy. Especially in cases where the initial versions of the tools have not been rigorously or extensively tested, evaluations should be conducted on an ongoing basis to determine if the tools provide the expected insight into the effectiveness of policies to affect some desired change. If the evaluations reveal weaknesses, they are also likely to provide guidance on the needed adjustments. It has been posited (and the EU has instituted policy) that country-wide computation of nutrient balances, such as nitrogen and phosphorus, are useful to assess progress toward achieving widespread sustainable agronomic production, as determined by the minimization of negative environmental impacts, within EU member states[15]. A similar, but much more local approach is being taken on a producer-by-producer basis by the USDA-NRCS[17]. There remains a question as to whether summing local N balance results across a region as large as an EU country (or across a US state such as Mississippi) is a useful exercise. There is also a question as to whether the N balance actually reflects local management decisions in response to economic drivers (including commodity prices and market and regulatory incentives), or is more responsive to factors outside human control (e.g., growing season weather variations or edaphic factors). This may be a case where a quantity that is easy to compute from the readily available official data is being misused or misinterpreted in some essential respects.

As Mississippi has converted farmland from cotton-to-corn, soybeans and wheat (Fig. 1A), the state-wide nitrogen balance has decreased overall (Fig. 7). The increase in area planted to corn, soybean and wheat in 2007 and 2008 enhanced N uptake, at least in part because of the higher coefficient of conversion of these crops, especially of soybeans. These changes in crop planting resulted from external influences of anticipated return on investment (Fig. 1C), which has been observed in other agricultural systems[12]. However, while shifting to different cropping systems may increase the economic return to an individual farmer in Mississippi, loss of processing associated with cotton negatively impacts the surrounding rural economy[34], negatively impacting a different aspect of sustainability. Moreover, environmental constraints of soil type and topography limited conversion of some fields to alternative crops (e.g., hay and rice). Given that conversion of all arable land to high-N-uptake crops is not a viable option in any sense of overall sustainability, the extent of possible improvement in N budgets due to such conversion is limited.

Additional improvements in crop production were also realized through better management and improved technology (cultivars, etc.) that enhanced crop yields in Mississippi (Fig. 1B), also directly contributing to greater N efficiency (Fig. 7). Conversely, lower yields in some years reduced the N uptake by crops, negatively impacting N efficiency in both Mississippi and Poland.

Poland is in the Continental environmental zone of Europe, the main attributes of which are severe winter periods and high year-to-year variability in water supply[42]. The most negative aspects of water supply are a high frequency of drought periods during the growing season, negatively affecting crops grown from April to September[43]. The sensitive drought period changes depending on crop: for winter cereals the worst is drought in April and May; for spring cereals—in June; for potatoes—in June and July; for maize—in July and for sugar beet—in July and August[44]. Drought that occurs during the most critical stages of plant growth is the most limiting factor to crop growth, in turn negatively affecting N use efficiency.

The emerging picture for Poland is one of increasing N inputs, due to increasing application of inorganic fertilizers and increasing livestock production (Fig. 4B), with only weak improvement in crop yields (Fig. 2B). The shift in cropping pattern from potatoes to cereals and rapeseed (Fig. 5B) has improved the total N uptake (Fig. 6B), but not sufficiently to produce an overall improvement in N balance (Figs. 6B and 7). The impact of poor crop weather appears to have been particularly important for Poland's total N balance. Moreover, increased use of N fertilizers has led to reduced N use efficiency[45]. The trend of increasing total N is troubling in every sense.

To address the increasing demand for meat protein, intensive animal production operations continue to expand. The establishment of confinement animal operations significantly increases the manure concentration in

an area, and the total nitrogen input to the production system. The geographic separation of animal and crop production systems in response to processing demands limits the distribution of nutrients across agricultural enterprises[10]. Integrated farming systems benefit the farmer and agriculture through resource sharing among enterprises[3,46]. As seen for the production systems in the northeast US, resource sharing provides benefits to the individual farmer, as well as the rural community[47]. This benefit is lost with vertical integration of an industry, as emphasis is placed on enhancing the subsequent stage or processing step rather than ancillary enterprises within the rural ecosystem[48]. The establishment of geographic regions of production based on processors' needs further exacerbates environmental contamination from confinement animal operations. Note that N budgets (as calculated herein) are nation or state-wide totals, and manure production correlates with poultry numbers (Figs. 3 and 4). Given the physical separation between cropped hectarage and confined poultry operations in Mississippi, it is possible that relatively strong improvements in N uptake in the Delta are masking the degrading conditions in the hill country due to cumulative N input. In other words, while the overall budget indicates improvement in N management, the local reality might be quite different. A similar situation appears to be developing in Poland[45,49].

Enhanced resource sharing between animal and crop production has been the norm in the semi-subsistence farms of Poland. As Poland moves toward more industrialized agriculture, including confinement swine production[9], the problem of manure disposal will become a greater concern. Most soils in Poland originate from sand and loamy sand materials, which are highly permeable to water and susceptible to leaching of nitrates[50,51]. Although the country average bonitation index of soil suitability for agriculture production, evaluated in the 100 degree rating, is approximately 66, significant regional differences in the index values are found[49]. Spatial differences in soil quality, inherent nutrient status and soil acidity result in differences in the use of fertilizers[49,52]. With diligent attention to use of locally generated manures as a substitute for artificial fertilizers, Poland has the opportunity to avoid the geographic separation that hinders resource sharing between animal and crop production enterprises in Mississippi and improve the overall N utilization in their agronomic production. Additional improvements in crop production and fertilizer use may be possible through better use of ancillary fertilizers such as magnesium, and liming to adjust soil pH[53,54].

Conclusions

This analysis assembles production and economic data across 11 years (1998 through 2008) from two very different agricultural production systems: a member of the EU (Poland) and the state of Mississippi, USA. The impact of within-season variability in production potential arising from weather and other variables, along with economic drivers, most notably commodity prices, on management decisions are evaluated within the context of annual assessments and trends of nitrogen budgets and gross nitrogen balance, as well as official and anecdotal evidence on spatial distribution and evolution of agronomic systems during this period. The gross annual N balances developed here clearly demonstrate the magnitude of difference in N balance, allowing an examination of two very different production systems. Trends in the annual N balance are also captured by the calculation, indicating changes in management practices.

Two problems with the use of large-scale nitrogen indices are revealed. The first problem is one of spatial scale: nitrogen indices calculated for large areas, such as a country or state, necessarily average out both the successes and problems in N management, obscuring the actual situation locally. The geographic separation of concentrated animal feeding operations (CAFOs) from crop production areas in Mississippi makes calculation of one index for the entire state inappropriate for within-state assessments or rectification planning. Spatial differences in gross annual N balances have already been observed for Poland[11]. The increasing establishment of CAFOs in Poland will further exacerbate the spatial variability of N budgets, rendering the use of nation-wide N indices similarly inappropriate.

The second problem is the sensitivity of nitrogen budgets and nitrogen use efficiency to actual crop yields. In years of poor crop performance, the calculated N budgets and gross annual balance do not reflect management choices. Valuation of ecosystem services can contribute positively through better implementation of conservation and alternative production methods[16,40]. However, establishing incentive payments or nutrient trading based on a factor that is not under the control of the producers, and cannot be forecast with a useful level of certainty, is clearly problematic. The acceptance and implementation of alternative management practices will be predicated on the extent to which this aspect of nitrogen budgets is recognized and accounted for in the application of incentives and trading schemes.

Coupled with the substantial anticipated world-wide growth of large-scale and intensive animal production systems[55], attention must be given to the management of nitrogenous wastes generated in these systems. Developing indices that capture and identify the year-to-year variability in drivers of the agronomic production system, both those that are under the control of producers as well as those that are not, and that reflect the spatial localization, will be needed as an indicator or policy instrument for achieving sustainable agronomic practices.

The goal of policy development directed toward quantifying agricultural impacts to the environment for

regulatory purposes is understood. However, that policy needs to be based on a realistic assessment of agricultural production and limitations to that measurement. Large, country or state-wide measures are a good starting point for exploring N impacts of agricultural production, but do not adequately reflect the local variations in N fluxes. Moreover, substantial N fluxes, such as those arising from the agriforestry industries, are currently ignored in the calculation of N indices. Improvements to agricultural production that address nutrient use efficiency will improve the overall nutrient balance of the system. Addressing problems closer to the source of problem development will go much further in reducing negative environmental impacts of agricultural activities.

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Book Review

Agriculture and Food in Crisis: Conflict, Resistance, and Renewal. Edited by Fred Magdoff and Brian Tokar. 2010. Monthly Review Press, New York. 348 p. Paperback, cloth US $75.00, paper US $18.95, ISBN 13 978-1-58367-226-6.

That doubling of food production over the next four decades will be needed to adequately nourish our human population is not news, but the incredible steps essential to achieve that goal and their political and social implications are less well reported. In this series of 16 essays edited by Fred Magdoff and Brian Tokar, several thoughtful specialists in global food issues explore the historical, biological, economic, energy, political and social dimensions of the current direction of development and their potential consequences for the future. The book provides a provoking and revealing perspective on the extent of challenges that must be overcome in reaching the daunting goal of feeding nine billion people.

From the opening words in Chapter 16 by Jules Pretty, eminent and prolific writer from the University of Essex,

> 'Something is wrong with our agricultural and food systems. Despite good progress in increasing productivity in the last century, hundreds of millions of people remain hungry and malnourished. Further hundreds of millions eat too much, or consume the wrong kinds of food, and it is making them ill. The health of the environment suffers too, as degradation of soil and water seems to accompany many of the agricultural systems we have developed in recent years. Can nothing be done, or is it time for the expansion of an agriculture founded on social science and ecological principles and in harmony with people, their societies and cultures?'

Professor Pretty clearly summarizes the challenge in both ecological and social terms. The editors and several authors point out the large advances in production achieved by the Green Revolution, yet observe in a contemporary reflection the broader consequences of an all-out effort to increase crop yields and economic returns in the short term. To be sure, we initially reduced prices for some basic grains, but now recognize many of the emergent properties of this process, such as longer-term challenges to health of the environment, to the well-being of many now-marginalized farmers and families, and to social equity in distribution of benefits in most developing countries where high-tech agriculture has been implemented in some areas.

Simultaneous with the introduction of new crop varieties and improved cultural practices, including increases in external inputs such as fertilizer and pesticides, an economic push toward neoliberal free markets fostered by massive loans from the IMF and World Bank to simulate economic growth has resulted in higher yields and increased trade in many places. Yet, these incentives based on an industrial agricultural economic model that ignored many local cultural and traditional methods and food systems, as well as political systems in place that disfavor people who are poor and/or live in rural areas, have resulted in greater inequities in incomes and access to food. Currently, agricultural imports are growing in many LDCs, agrofuels and growing demand for grain for livestock consumption are pushing up grain prices, and there is loss of food sovereignty in many countries. This puts poor countries at a tremendous disadvantage in a globalized food system, and increases the probability of food shortage and social unrest. Those people who are poor suffer the most from lack of local food sources and opportunities for gainful employment.

Through the book, a number of current issues are explored and evaluated: production of food crops for local consumption versus commercial crops for export, food used for fuel versus that produced for direct consumption, inefficiencies of conversion of grain to meat—especially by ruminant livestock—and, most recently, the massive neocolonial land grab that is transferring control and sometimes ownership of large tracts of land in Africa, South America and South-East Asia into the hands of land-poor but cash-rich countries such as China and Saudi Arabia. Lest those of us in US universities feel smug and self-righteous about this not being any of our doing, we need to know that our own TIAA-CREF retirement fund is invested in some international companies involved in land acquisition. We are all part of this global economy, and we bear some moral responsibility to understand what is happening and what alternatives are available.

These issues have all been raised before. The most useful sections of each chapter are those that offer viable alternatives to the current march of agricultural and food system development. There are models described from Brazil, Ecuador, Venezuela, Guatemala and Mexico that illustrate the potential productivity and profitability of small farm systems that are biodiverse, traditional and based on current rainfall and solar energy rather than expensive imported inputs. We know from observation and measurement that the production efficiency per unit land in some of the better systems is greater than on those farms using intensive inputs, large fields and high

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technology. We have little information about the long-term potential of improving ecologically based systems using appropriate technologies because so little research has been done on them. An alternative strategy for development and improvement of traditional systems is advocated as one solution to the challenges presented by pursuit of a single industrial model.

The various chapters in this book view the challenge from multiple angles: how to increase productivity and production, how to move toward more equitable economic distribution of incomes and food, how to achieve our massive goal of feeding people while preserving the environment and how to do all this in a socially and politically acceptable way. One of the strong features of the book is the strong multidisciplinary focus, and the obvious message that it will take many people and groups working together to achieve the food sufficiency and food sovereignty that will provide lasting benefits to the global population. The authors are not anti-science, nor are they against development. But the clear message is that we should not continue to pursue and protect a system that is not currently feeding the world's population in an adequate way, and that we are unlikely to achieve that goal if we continue on the same path. There is valuable insight here that could be useful in courses in agroecology, rural development, agricultural economics and natural resources. It would be most applicable to upper division courses or to beginning graduate students, but *Agriculture and Food in Crisis* has lessons that are valuable to anyone interested in the future.

Charles Francis, University of Nebraska—Lincoln, Nebraska, USA
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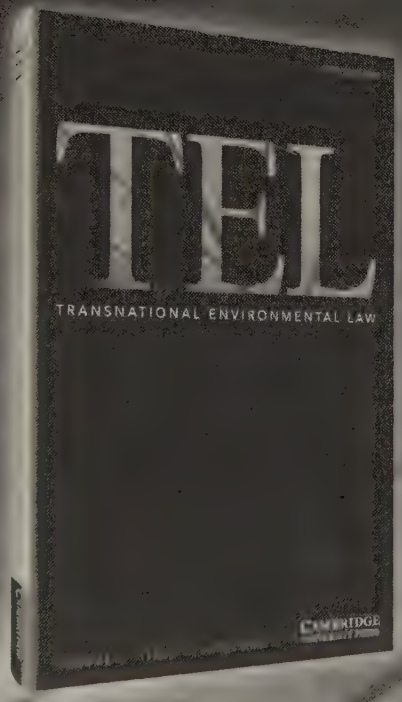

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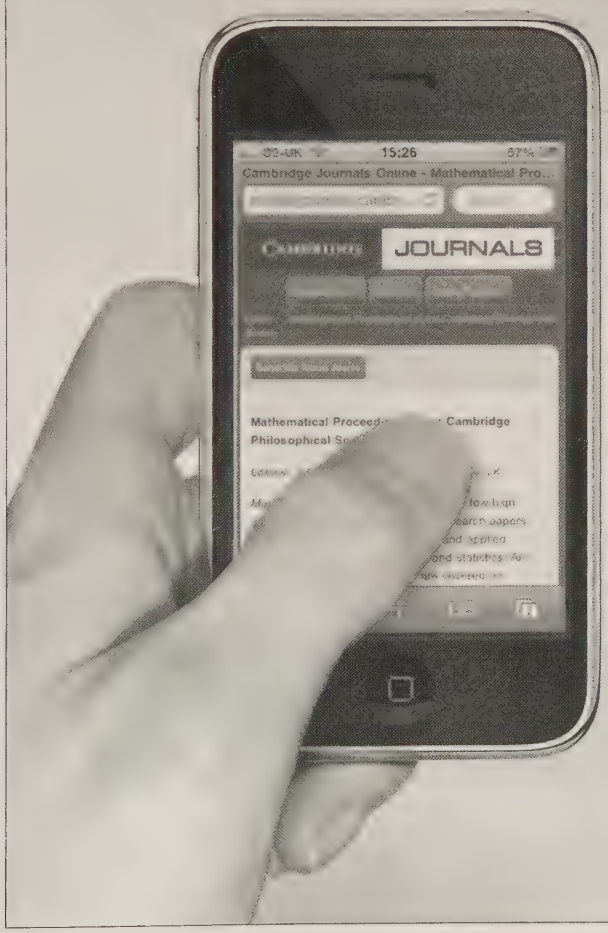

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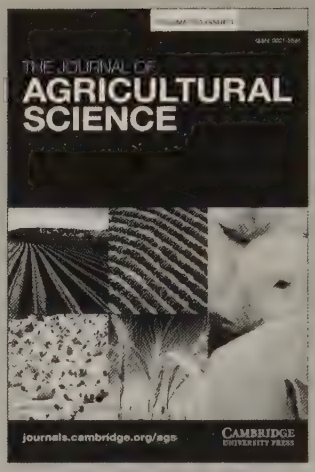

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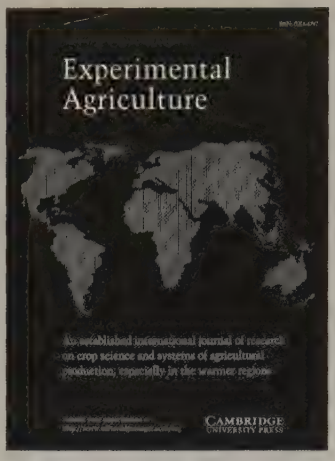

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Experimental Agriculture publishes the results of original research from any source on the agronomy of field, plantation and herbage crops grown for human or animal food; for industrial purposes; and on systems of agricultural production, particularly in the warmer regions of the world. It is especially concerned with experimental work designed to explain agronomic results in biological and environmental terms. The journal publishes accounts of new experimental techniques, new methods of crop production and discusses problems in countries where production is developing rapidly. There are regular book reviews and occasional, often invited, reviews of research.

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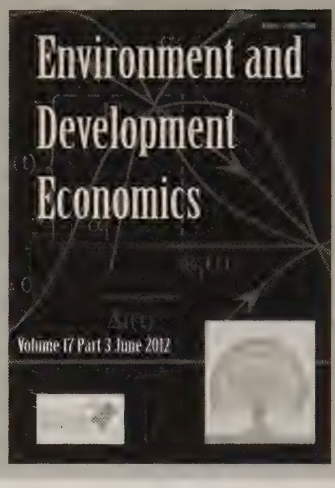

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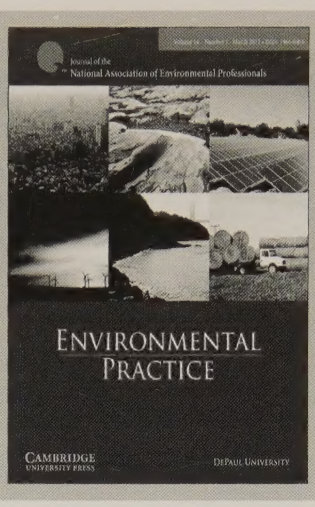

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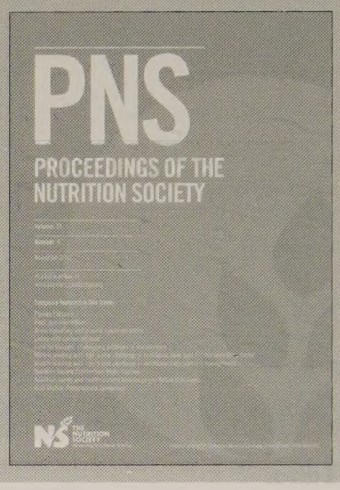

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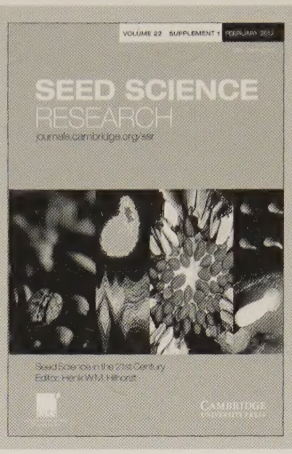

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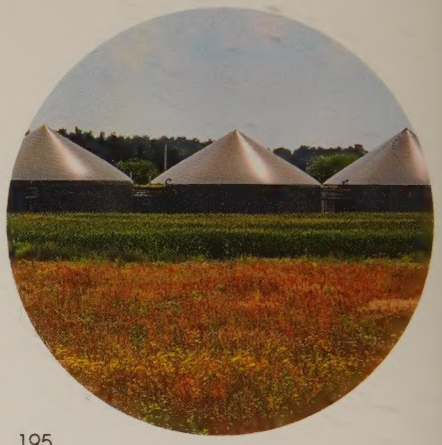

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